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FOREWORD

In the preface to Herb. Publ. Ser. Bulletin 14 on "Grassland Research in Australia," issued in 1934, William Davies drew attention to the vast area included in the natural and sown pastures of Australia, to the distances which made frequent personal contact between workers both costly and difficult, and to the wide range of conditions, marked aridity to heavy rainfall and tropical to temperate climate, which is characteristic of the continent.

In area the country is about two-ninths of the British Empire, is exceeded in size only by U.S.S.R., China, Canada, Brazil and U.S.A., and is larger than Europe less Russia.

About forty per cent lies within the tropical zone, and rainfall varies from 165 inches per year on the north-east coast of Queensland to an annual average of 5 inches in the Lake Eyre district of South Australia. Over one-third of the continent receives less than 10 inches of rain on the average annually, and just under one-third between 10 and 20 inches. Less than one-seventh receives 30 inches or more, this of course including the high country, and probably on not more than one-sixth of the area of the continent is pasture improvement feasible.

It would be expected, therefore, that Departments of Agriculture would make their greatest effort in the better rainfall areas, and indeed most of the officers engaged in grassland work (about fifty) operate in areas where it requires less than two acres to maintain a sheep. The general programme of pasture investigations covers two main features, natural pastures where maintenance and regeneration are essential, and sown pastures where the proper treatment of exotic species is necessary. Both these aspects and, in addition, the problems of the winter and the summer rainfall pastures, are dealt with in this bulletin.

Part II presents the Departments and Institutions which are engaged in pasture work and a brief outline of the main features of their programmes. Part III contains fifteen special articles, dealing with subjects ranging from a survey of the Australian environment to somewhat more detailed outlines of the work in progress in each State. Part IV contains brief abstracts of recent publications on grassland in Australia.

Canberra, November, 1939.

I. THE INSTITUTIONS AND DEPARTMENTS

A. Commonwealth Council for Scientific and Industrial Research

The Division of Plant Industry of the Council for Scientific and Industrial Research undertakes the greater part of the grassland research conducted by the Council and the investigations are made by three sections of the Division.

The section for Plant Introduction is responsible for the search for a wider range of herbage species for use in the Commonwealth, with particular emphasis on leguminous herbage species. The initial tests of the introductions are made at three centres—Canberra ; Gatton College, 60 miles west of Brisbane ; and Rockhampton, in a typical subtropical coastal area. The more promising plants are further tested in collaboration with the various State Departments of Agriculture and private individuals, thus covering a representative range of climatic and soil conditions. Hitherto no introduction has found any place in agricultural practice because of the relatively short period that the plants have been available (work commenced in 1930).

The Plant Genetics section is engaged in the selection and breeding of improved strains and varieties of the more important herbage species, with especial emphasis on the species found valuable in the marginal areas lying between the pastoral areas and the zones of higher effective rainfall. Thus in Southern Australia—the winter rainfall belt—attention is devoted to the species of the genera *Danthonia*, *Medicago* and *Trifolium* found of primary importance in the pastures growing between the 15 and 25 inch isohyets. This work is centred at Canberra (22 inch rainfall). For the semi-tropical conditions of the coastal and sub-coastal areas the crops studied are lucerne (*Medicago sativa*) and its affinities ; Rhodes grass (*Chloris gayana*) and *Phalaris tuberosa* ; *Trifolium pratense*, *Trifolium repens*.

The Agrostology section is a more recent development made possible by a grant from the Australian Wool Board. Emphasis is laid on the improvement of pastures in the semi-arid pastoral areas and on sheep pastures generally. Surveys of the pasture problems in the South Western Division of Western Australia and of the Southern areas of Queensland have been undertaken and a programme of investigations, including ecological and grazing studies, has been drawn up. The relation of food supply to the health and nutrition of the grazing animal is being particularly stressed and the agrostological investigations are planned in collaboration with the Division of Animal Health and Nutrition.

The Division of Animal Health and Nutrition is not primarily engaged in pasture research, but in the course of studies on both nutrition and internal parasites, questions of pasture mixtures and grazing management have become insistent and several wool and grazing studies have provided valuable information on sheep pastures. Research on supplementary feeding, both of minerals and protein deficiency, although not directly concerned with the pastures themselves, are nevertheless important because of the great difficulties in providing a uniform and adequate stock food supply in the pastoral areas.

B. New South Wales

Pasture investigations are the function of the Agrostology Branch, while the selection and breeding of certain pasture and herbage species are a major activity of the Plant Breeding Branch of the State Department of Agriculture.

The Agrostology Branch is primarily concerned with the extension and educational side of its activities ; in doing so, it undertakes a wide range of agrostological investigations covering the improvement of pastures generally. These trials are centred at the various State Experimental Farms and Hawkesbury Agricultural College, Richmond. In addition, the District Agrostologists conduct demonstrations and trials on private holdings throughout the State.

The Plant Breeding Branch is engaged on the breeding of lucerne (*Medicago sativa*) and the breeding and selection of strains of pasture plants suitable for various climatic conditions in New South Wales. The pasture plants include *Lolium perenne*, *Phalaris tuberosa*, *Dactylis glomerata*, Wimmera ryegrass (*Lolium rigidum**), Hooker's fescue (*Festuca Hookeriana* F. v. M.), Sudan grass (*Andropogon sorghum* var. *Sudanensis*), *Trifolium pratense*, *T. repens*, *T. subterraneum* and *Medicago lupulina*. In addition, interspecific and intergeneric crosses are being explored with the object of evolving new pasture species.

C. Victoria

The Victorian Department of Agriculture has conducted an extensive series of investigations into questions of pasture improvement, including the establishment, maintenance and management of irrigated pastures ; the improvement of natural swards by fertilizers, cultivation and the incorporation and encouragement of legumes in the sward ; the extension of sown pastures. The greater part of Victoria enjoys a reliable rainfall, dominantly a winter rainfall type, but the cool temperate climate provides a long growing period, while in Gippsland growth is active during the greater part of the summer period. The extension of activities on pasture research has included the study of herbage plants suitable for the climatic conditions experienced in the Mallee areas in the drier north western belt (Walpeup, Victoria). The main centre of investigations is Werribee State Research Farm, 20 miles south of Melbourne, where the main experiments on irrigated and sown pastures are based ; plant breeding and selection on the more common herbage species, *Lolium perenne*, *Dactylis glomerata*, *Phalaris tuberosa*, *Trifolium repens*, *T. subterraneum*, *T. pratense* and *T. fragiferum*, together with ancillary work, are located at Burnley Gardens in the outskirts of Melbourne. A comprehensive series of tests of pasture species and mixtures and their management has been instituted throughout the State under the aegis of the Pasture Improvement League, in which the technical services are provided by the Department of Agriculture. Investigations on grazing management, establishment of seeds mixtures and their subsequent fertilization and carrying capacity are being undertaken at Rutherglen State Experiment Farm, while questions of suitable herbage species and strains and the problems of their establishment

*The status of the specific name of Wimmera ryegrass is still not fully established and it has been given amongst others *L. subulatum* ; *L. rigidum* var. *strictum*.

and persistence are being studied at the Walpeup Research Station, in the North Western Mallee areas.

D. Queensland

(a) Department of Agriculture and Stock

Investigations on Queensland pastures have not for many reasons been as intensive as in the older southern States. The Department of Agriculture and Stock has by demonstration and investigation encouraged the use of *Paspalum dilatatum*, *Chloris gayana*, *Brachiaria mutica*, *Melinis minutiflora* and *Panicum maximum*, the last three species proving of great potential value in the northern tropical coastal belt. The use of artificial fertilizers, on both sown and native swards, has not given economic results comparable with those in Southern Australia, but the renovation of sod-bound swards of *Paspalum dilatatum* by ploughing, and the successful use of Rhodes grass (*Chloris gayana*) in short term rotations with cotton have been notable improvements in pasture production and utilization. The export of chilled beef in recent years, made possible as the result of technical improvements in the long-distance carriage of chilled meat, allied with the control of redwater disease of cattle, have called for greatly increased facilities for the fattening of beef cattle. Investigations on the production, feeding value and management of pasture mixtures for cattle fattening have recently been commenced on the tropical coast, and it is proposed to intensify this phase.

The breeding and selection of herbage species have by agreement been regarded as functions of the Division of Plant Industry of the Council for Scientific and Industrial Research (hereafter C.S.I.R.).

Since 1936 the question of pasture deterioration on the semi-arid western plains has been studied ; grazing trials and life history studies of the main pasture species are in progress.

(b) Queensland Agricultural High School and College, Lawes, Queensland

The pasture research programme of the College itself is not extensive. A study of the effect of phosphatic fertilizers on the yield, botanical and chemical composition of a natural sward was concluded in 1930 and reported upon. Grazing trials are in progress with *Chloris gayana*, *Phalaris tuberosa* and *Medicago sativa*, in which these herbage plants are compared with the summer cereals (maize and sorghums) as the basis for feeding dairy cattle on the black soils of the Lockyer Valley.

The College is collaborating with the C.S.I.R. in its programme of plant introduction, plant genetics and agrostology, a substation of the Division of Plant Industry being established at the College.

E. South Australia

(a) University of Adelaide

1. Waite Agricultural Research Institute

The Institute has devoted itself since 1928, following its inception in 1925,

to research on dryland pastures, with particular reference to the investigation of the mineral content of pastures. Studies in this field subsequently led to a marked expansion of the work, which was stimulated by the lack of basic information relating to the general problem of pasture improvement.

The investigations now in progress cover a wide field, including problems of establishment, fertilization and management, with especial emphasis on grazing management of sown pastures over a range of soil and climatic conditions, as well as the study of the natural pasturages in the arid pastoral areas with a mean annual rainfall of 7-10 inches per annum.

Supplementing the general programme, the selection of improved strains of the comparatively few useful sown species is being undertaken, while the study of the relationship between the legume and its symbionts is an important phase of study. A concise account of the pasture research in progress at the Institute is given by H. C. Trumble (pp. 57-60).

2. Botanical Department

The Botanical Department of the University is engaged on two phases of research of primary importance to the agriculturist: (1) the regeneration of the dominant plants in the arid pastoral areas of South Australia; (2) drought resistance. The first is essentially ecological research, the second physiological.

(b) Department of Agriculture

Grassland investigations were first commenced in 1919 and are based mainly at the Kybybolite Experiment Station in the south east of the State, but experimental and demonstration work is being undertaken throughout the more favoured rainfall areas. The Department works in collaboration with the Waite Institute and is itself mainly concerned with the establishment, fertilizing, management and carrying capacity of pastures in which *Trifolium subterraneum* is the legume, and the search for persistent associate grasses under practical farming conditions. Studies of the effect of different fertilizer treatment of both sown and natural swards on the live-weight, wool production and capacity for fat lamb production of such swards have been extremely valuable. Some attention has been devoted to selection of certain herbage species, while the fostering of lucerne growing and of fodder conservation are important phases of activity. Seed certification of proved strains of *Trifolium subterraneum* (Mount Barker Mid-season type); *Medicago sativa*; *Trifolium fragiferum*; *Lolium rigidum* (Wimmera ryegrass); *Phalaris tuberosa*; *Lolium perenne* and *Oenothera latifolia* (evening primrose) has been placed on a working basis.

F. Tasmania

Department of Agriculture

The pasture problems in Tasmania are more closely related to those of New Zealand and Europe, and production is limited principally by extremes of temperature, rainfall being in general a subsidiary factor. Investigations have been directed

to the improvement of the lightly timbered natural swards by surface seeding of *Trifolium subterraneum*, followed by phosphatic fertilizers ; and to the sowing down of pasture species after ploughing—generally a mixture of *Lolium perenne*, *T. subterraneum* and *T. repens*.

In the agricultural districts of mixed farming, the use of suitable seed mixtures for the production of both temporary and long duration leys has been studied. Work recently instituted is concerned with the grazing management of such improved swards, allied with questions of fodder conservation and supplementary feeding of stock for the periods of low production in winter. (Certification schemes have been instituted for *Lolium perenne* and *Trifolium subterraneum*.)

G. Western Australia

Department of Agriculture

Until recently, the main activities of the Department have been directed to the improvement of dairying pastures of the wet south western area of the State—characterized by a relatively heavy winter rainfall and soil of very low fertility—and to problems associated with the establishment of pastures in the three main irrigation areas of the western coastal plain, comprising some 60,000 acres.

On the irrigation areas, attention has been devoted to suitable species and seeds mixtures, and their fertilization and watering. With the lower prices for wheat and the development of the fat lamb industry—for which industry there are extensive areas of suitable, but only partially developed land—the question of pastures in the areas enjoying a much shorter effective growing season has been investigated. The discovery and exploitation of the early-flowering strains of *T. subterraneum* (notably Dwalganup) have provided the means whereby pasture improvement has become possible where mean rainfalls are about 16 inches per annum.

Institute of Agriculture—University of Western Australia

The Institute has since 1937 been investigating the seasonal variation in the food production and value of " Spinifex " pastures in the Port Headland district in N.W. Australia, with special reference to the effect of fire and rotational grazing on the sheep-food supply.

In 1939, the C.S.I.R. began a series of trials in co-operation with the Institute, designed for the improvement of the sheep pastures in the winter rainfall belt of the south western areas. The testing of associate grass species and grazing management investigations are in progress, together with life history studies of *Ehrharta calycina* and *Lupinus* spp., both species being of great potential value on the extensive light low-fertility soils in the State.

H. Other Bodies

Australian Estates Co., Ltd.

This Company, in common with other large pastoral companies, is the owner of and financially interested in a large number of properties throughout the more

arid pastoral areas. The Company has instituted a vigorous policy of investigation into the problems confronting it in regard to both pastures and stock. Much of the work is in co-operation with officers of the C.S.I.R. and other research bodies. The features being investigated are the drought feeding of sheep with especial attention to the protein and phosphate supply, known to be deficient in the pasturage.

Trials of the more common species, together with the effects of phosphatic topdressing on natural swards in certain of the Company's properties are in progress, while experimental surveys of lucerne, field peas and fodder crops, designed as food supplements, are being made.

In Western Queensland a study of the yield and composition of Mitchell grass pasture (*Astrebla* sp.)—a co-operative investigation with the Waite Research Institute—provided valuable information on the possibilities of fodder conservation in the pastoral areas and the rapid deterioration in nutritive value of the bulk of standing summer-grown herbage.

II. SPECIAL ARTICLES

1. THE AUSTRALIAN ENVIRONMENT IN RELATION TO GRASSLAND

J. Griffiths Davies

Five thirteenths of the total area of Australia (2,971,804 square miles) lies within the Tropic of Capricorn, and includes rather more than one half of the combined areas of Western Australia, Queensland and the Northern Territory. 1,825,000 square miles are in the temperate zone, Tasmania lying almost wholly south of latitude 41°S ; and the greater part of Victoria—the most southerly State of the mainland—is south of latitude 35°S. Because it is an island continent situated mainly in the warm temperate zone and lacking striking physical features, Australia is, on the whole, less subject to extremes of climate than are regions of similar area in other parts of the globe.

On the coast—more particularly the eastern Pacific coast—the rainfall is often abundant, the wettest area being on the north-east coast of Queensland on the Johnstone and Bussell Rivers, where average rainfalls in excess of 140 inches per annum occur. These wet districts are small and insignificant in area compared with the bulk of the continent, arid and desert conditions prevailing over tremendous areas of the interior.

Rainfall

The amount of rainfall and the variability of its incidence are the two major determinant climatic features. Temperature range is not great, practically the whole falling within the two zones of warm temperate and hot climates. Fig. 1, prepared from the records of the Commonwealth Meteorological Bureau, shows the main features of the annual rainfall, and also the line of approximately equal winter and summer rainfall incidence. South of the line, winter rainfall becomes increasingly dominant and there is a distinct trend toward a shorter wet season in a westerly direction. The rainfall in the southern zones is more reliable in its incidence than in the northern zones. The important isohyet south of the line is the 15 inch isohyet. Northward to Queensland, because of the lowered efficiency of the summer rainfall for plant growth, the 25 inch isohyet must be regarded as the minimum annual rainfall under which pasture improvement by existing methods can be expected.

The use of the annual rainfalls as a measure of the limitations imposed on plant growth is not entirely satisfactory, and several workers, notably Prescott (**4**), Davidson (**1**) and Trumble (**5**), have used the Meyer ratio and the ratio of precipitation to evaporation from a free water surface, relating the latter to saturation deficit. Trumble has mapped the southern States, using the figure of $0.\dot{3}$ for the ratio P/E, and relating the growing season of certain pasture plants to the "influential rainfall period," which he defines as the length of time in which P/E exceeds $0.\dot{3}$. Prescott in his climatic study of tropical Australia uses two values of the Meyer ratio to define the effective growing period. The Meyer ratio has to exceed a value of 5 for any month, and for effective growth a value of 35 has to be attained during some portion

FIG. 1.

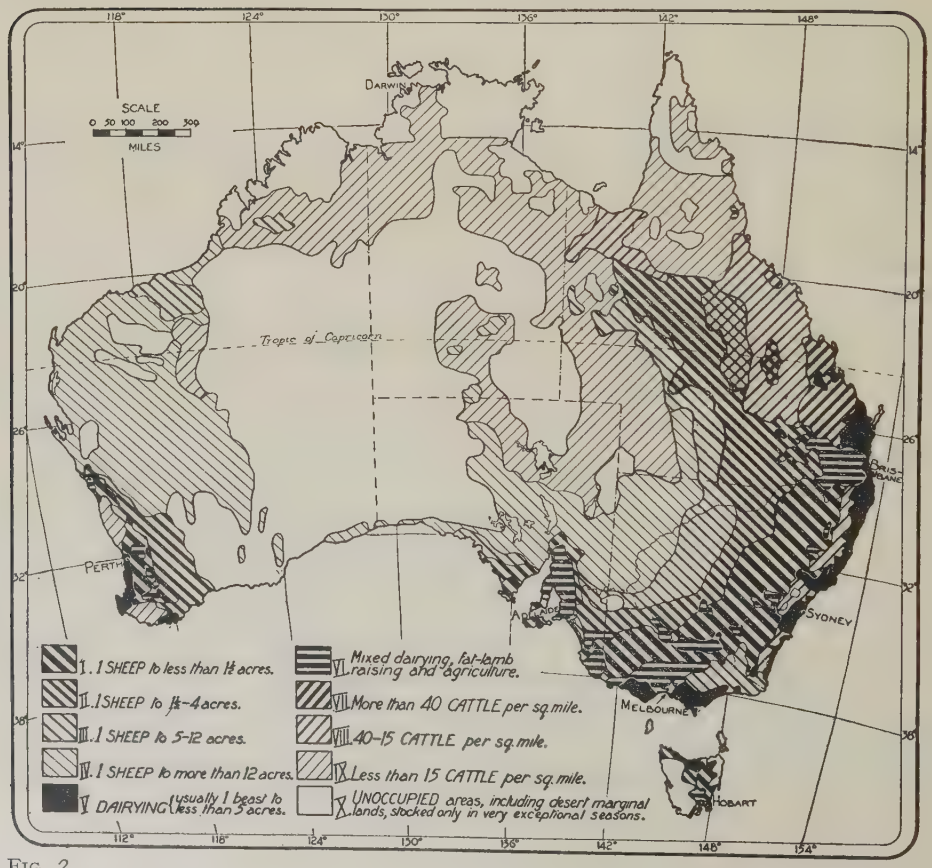
SCALE
0 50 100 200 300
MILES
DARWIN
Tropic of Capricorn
PERTH
ADELAIDE
SYDNEY
MELBOURNE
HOBART
I. 1 SHEEP to less than 1½ acres.
II. 1 SHEEP to 1½–4 acres.
III. 1 SHEEP to 5–12 acres.
IV. 1 SHEEP to more than 12 acres.
V DAIRYING (usually 1 beast to less than 3 acres.
VI. Mixed dairying, fat-lamb raising and agriculture.
VII. More than 40 CATTLE per sq. mile.
VIII. 40–15 CATTLE per sq. mile.
IX. Less than 15 CATTLE per sq. mile.
X. UNOCCUPIED areas, including desert marginal lands, stocked only in very exceptional seasons.

FIG. 2.

FIG. 1.—The main isohyets in Australia. (Compiled from the records of the Commonwealth Meteorological Bureau.)

FIG. 2.—The density and type of stock population in Australia. (Prepared by the Economic Branch, Bank of New South Wales and re-published with

of the growing period. In the winter rainfall zone, the criterion of P/E as used by Trumble gives a valuable indication of the period of growth of pastures, but in the summer rainfall zone the agreement is not as good—partly because of the difference in the nature of the rainfall incidence and partly because of the different character of the pasture flora.

The Soil Factor

The soils of Australia have been classified by Prescott (**3**) into ten groups. Of these groups, the podsols, red-brown earths, the black and the red soils are situated mainly in the moderate to good rainfall zones where pasture improvement is practicable and economic. The grey and brown soils are in the drier areas. The podsols and red-brown earths are deficient in phosphate and nitrogen, and pasture improvement on these soils is therefore closely linked with the use of phosphatic fertilizers and pasture legumes.

The Scope for Improvement of Pastures

Pasture improvement can be regarded as feasible only on a comparatively limited proportion of the almost three million square miles of Australia. The extensive areas of the arid interior are too dry and their carrying capacity is too low to warrant the capital expenditure involved in improvement by fertilization or in sowing, while it is unlikely that any introduced species can withstand the environmental and grazing factors as well as the endemic species. An estimate of the gross area in which pasture improvement is climatically possible can be made by using the area enclosed by the 15 inch isohyet in the Southern States and the 25 inch isohyet in Queensland. In northern Western Australia and the Northern Territory, there is no information available to suggest that any very material improvement in pasture is possible ; these areas are therefore not included, although many thousands of square miles receive rainfalls in excess of 25 inches per annum.

The area in each State subject to different rainfalls is given in Table I taken from the Commonwealth Year Book, No. 30.

Table 1. Average Annual Rainfall Distribution.
(Areas in square miles.)

Average annual rainfall (inches)	New South Wales	Victoria	Queensland	South Australia	Northern Territory	Western Australia	Tasmania	Commonwealth
Under 10	48,749	nil	80,496	310,660	140,500	486,952	nil	1,067,357
10 to 15	78,454	19,270	81,549	36,460	132,780	255,092	nil	603,605
15 to 20	55,762	13,492	111,833	19,940	63,026	94,101	304	358,458
20 to 25	45,140	14,170	143,610	8,620	49,157	44,340	3,844	308,881
25 to 30	30,539	15,579	99,895	3,258	41,608	31,990	3,016	225,885
30 to 40	33,557	14,450	61,963	1,036	37,642	59,520	5,027	213,195
Over 40	18,171	10,923	91,154	96	58,907	3,925	11,247	194,423
Total area	310,372	87,884	670,500	380,070	523,620	975,920	23,438	2,971,804

The whole of the area receiving less than 15 inches per annum must be regarded as too dry for effective pasture improvement, and deducted from the total, while the total area of the Northern Territory must be deducted as noted above. In Western Australia, of a total of 240,000 square miles having a rainfall exceeding 15 inches, only 50,000 square miles are in the southern winter rainfall belt. In Queensland, pasture improvement cannot be expected below the 25 inch isohyet, thus leaving a gross area of 253,000 square miles in that State.

The estimate of gross area capable of improvement in each State is given in Table 2.

Table 2. Estimated gross area suitable for pasture improvement, based on mean annual rainfalls.

	square miles.
New South Wales	183,169
Victoria	68,614
Queensland	253,000
South Australia	32,950
Western Australia	50,000
Tasmania	23,438
Commonwealth total	611,171

The area of 611,000 square miles includes physical features such as high mountains, steep slopes and gorges, roads, rivers, city and town areas which are not estimated. In Victoria, mountain ranges account for some 17,000 square miles. In Tasmania some 12,000 square miles or over half the State (**2**) are too rugged for permanent occupation. In addition the greater part of the areas under crop and cultivation is included in this estimate of gross area. This aggregates a further 20,000,000 acres or 31,000 square miles. Thus, the net area of land available for pasture improvement is not much more than half a million square miles, or approximately one-sixth of the total area of Australia; even on this area, however, much intensive research and investigation are needed. This is indicated by the figure of 4,000,000 acres of pasture lands topdressed with artificial fertilizers in 1935-36, over half of which was situated in Victoria.

In the semi-arid pastoral areas, on which the carrying capacity is below a sheep to 1.5 acres (Fig. 2), the prevention of deterioration of the plant cover by exploitative grazing is the most important phase of pasture research. The floras of these extensive areas are imperfectly understood, while practically no systematic information is available regarding the effects of the grazing animal on the plant cover.

The Carrying Capacity of Australian Pastures

One of the most instructive general maps of Australia showing the density and type of the stock population has been published (**6**) by the Economic Branch of the Bank of New South Wales (Fig. 2) from its records. The map is based on the records of agricultural and pastoral holdings in which the Bank is financially interested, and its wide interests probably give an excellent sample of the whole stock distribution. In Western Australia, the Northern Territory and Northern Queensland,

the rate of stocking is very low, consisting mainly of cattle at less than 15 beasts to the square mile. Large tracts of Western Australia and South Australia carry less than one sheep to 12 acres ; actually the bulk of these areas carries one animal to about 20 to 30 acres.

Pasture Improvement

Pasture improvement has developed along four main lines :

1. The use of superphosphate and subterranean clover to raise the carrying capacity of the southern coastal pastures of the podsols and red brown earths, thereby overcoming the deficiency of soil phosphate and nitrogen.
2. The sowing of pasture mixtures mainly confined to the areas of liberal rainfall devoted to coastal dairying. The available pasture species are very restricted and will be briefly enumerated below.
3. Improvements in methods of pasture management, use of rotational grazing and conservation of fodder supplies.
4. The recognition and selection of improved strains of pasture species.

These developments have been restricted almost entirely to zones I, II, V and VI in Fig. 2, i.e. the higher sheep carrying areas and the dairying and mixed farming areas. This is partly because the species available have been the recognized pasture species of the cool temperate climates, such as *Lolium perenne*, *Dactylis glomerata* and *Trifolium repens*, and species from the moist temperate areas such as *Paspalum dilatatum* and *Chloris gayana*. It is also partly due to the fact that *T. subterraneum* and other annual legumes will grow and respond well only in areas with a dominant winter rainfall and where the wet season exceeds five months of the year (**5**).

The legume used most extensively is the annual self-regenerating species, *Trifolium subterraneum*, which is regarded as an ecotypical selection from accidentally introduced parent material. The plant is self-fertile and wide variation exists within the Australian material. This variation is being extensively studied and several distinctive varieties are already in commerce. One of the most interesting and valuable is the early-flowering strain, "Dwalganup," which has made possible the successful use of the clover on areas where the average wet season is only 5 to 5.5 months. This compares with a requirement of over seven months for the original mid-season strain of " Mt. Barker" subterranean clover. The legume is particularly valuable on the podsolized soils, which are very low in fertility in their virgin state.

Lucerne (*Medicago sativa*) is grown extensively in all States except Western Australia, and is probably the best-known legume. Its requirements are, however, satisfied only on the best soils and, because of its deep rooting habit, it is being further exploited in dry areas, using low seeding rates. Any further great extension of its use cannot be expected.

In the main dairying areas, where the wet season exceeds nine months of the year, white clover (*Trifolium repens*) is used successfully in conjunction with perennial ryegrass (*L. perenne*) in Victoria, and with *Paspalum dilatatum* on the eastern coast. In favoured areas on the Tablelands of New South Wales, the combination of perennial ryegrass and white clover is also successfully used. Red clover (*T. pratense*)

and strawberry clover (*T. fragiferum*) are of limited value on especially favoured alluvial coastal flats. Several other annual legumes are common constituents on land that has been topdressed with superphosphate; these include *Trifolium glomeratum, T. resupinatum, T. procumbens, T. tomentosum, T. cernuum, T. scabrum* and *T. striatum*. The annual medics, *M. denticulata* et vars., *M. minima, M. laciniata, M. tribuloides, M. maculata* are widely distributed and common on cultivated lands and in the wheat-growing areas. *M. denticulata, M. minima* and *M. laciniata* are important components of the "winter" phase of the flora of the black and grey soils of New South Wales and southern Queensland, and even extend as ephemerals into the flood plains of the semi-arid areas. The medics do well in alkaline soils and appear to be able to mature in a shorter rainy season than the clovers. Several species of *Lotus* are useful in very restricted wet localities. It is a striking fact that every legume mentioned is a naturalized introduction, the majority of them accidental introductions. Hitherto no endemic legume has been found of much importance in our pastures, and none has been sown commercially.

Pasture improvement in the semi-tropical and tropical areas of the eastern coast of Queensland has been seriously hampered because of the absence of a suitable legume. Phosphatic fertilizers have given little or no response on pastures, partly because there is no legume and partly because of the "fixation" of the phosphates in the soil. In certain circumscribed areas near Brisbane and on the Atherton Tableland, white clover has proved of some value, but generally speaking Queensland pastures are entirely gramineous. In the tropical areas of the north coast, *Melinis minutiflora, Panicum maximum* and *Brachiaria mutica* are valuable pasture grasses. On the sub-coastal intermountain region, Rhodes grass (*Chloris gayana*) grows successfully, but in the absence of a legume the swards deteriorate more or less rapidly. The grass produces heavy yields but is not very palatable to stock, especially in the later stages of growth, and it is neglected from flowering onwards.

Irrigated Pastures

The development of irrigation on the main river system of the Murray and its tributaries has brought nearly three quarter of a million acres of otherwise low-carrying pastoral lands under intensive production. Smaller irrigation schemes have been developed in Victoria and in Western Australia. Originally the main irrigation areas were developed for fruit and vine-growing, but the restricted markets, as well as other difficulties, have tended to make pastures of greater importance. The areas in Southern Victoria and in Western Australia were, however, originally designed for dairying and it seems inevitable that any further extension of irrigation, more especially in the Murrumbidgee Irrigation Areas of New South Wales, will be devoted to pastures for dairying, fat lamb production and even for supplementing the natural pastures in wool growing.

Of the total areas of 740,000 acres under irrigation in Australia, nearly 500,000 acres are in Victoria. Cereals (including rice), orchards, vineyards, and other cultivated crops, including sugar cane in Queensland, account for some 315,000 acres. Lucerne, grasses and green fodder crops are grown on 200,000 acres, the remaining

areas being devoted to permanent pastures. A small but unestimated area of fallow is included in the pasture area. Extension of the irrigated areas is in progress on the Murrumbidgee Irrigation Areas in New South Wales. It will be possible to reticulate water through a total area of nearly six million acres. The whole of this area cannot, however, be uniformly irrigated ; each farm holding will have water rights available on a proportion varying from one-sixth to one-eighth of its total area. This limitation is imposed by the total water available in the watersheds. On this area alone the present acreage under irrigation can be doubled.

Lucerne is the most extensively used herbage plant under irrigation, but for grazing purposes perennial pasture mixtures are increasing in favour. Lucerne, generally as a pure stand, gives the highest yields of nutrients under a system of hay cutting.

Where ample and continuous water supplies are available, the best grazing mixtures are based on perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*), with cocksfoot (*Dactylis glomerata*) as a common constituent. Strawberry clover (*Trifolium fragiferum*) red clover (*T. pratense*) and prairie grass (*Bromus unioloides*) are also commonly added under special circumstances. Purely as a summer producing pasture, a mixture of *Paspalum dilatatum*, *Lolium perenne* and *Trifolium repens* is frequently used. This mixture requires great care in management and grazing, as the sward quickly becomes sod-bound. *Paspalum* swards will, however, resist heavy grazing and are also valuable in being able to carry stock immediately after watering. Because of this latter feature, *Paspalum* swards are used to avoid trampling injury to other pasture mixtures.

Frequently continuous water supplies are not available. In these cases, two mixtures have been found to be useful, both based on *T. subterraneum*. The first is a mixture of Wimmera ryegrass (*Lolium* sp.) and *T. subterraneum*—valuable when the water supply is restricted to autumn and spring—and the second is *L. perenne*, *Medicago sativa* and *T. subterraneum*, a valuable mixture where intermittent summer irrigation is possible.

References

1. Davidson, J. Bioclimatic zones of Australia. *Trans. roy. Soc. S. Aust.* 60. 1936.
2. Lowndes, A. G., and Maze, W. H. Land utilization regions of Tasmania. *Univ. Sydney Publ. Geogr.* No. 4. pp. 1-29. Sydney, 1937.
3. Australia, Council for Scientific and Industrial Research. Bulletin No. 52. The soils of Australia in relation to vegetation and climate. *By J. A. Prescott.* Melbourne, 1931. pp. 82.
4. Prescott, J. A. The climate of tropical Australia in relation to possible agricultural occupation. *Trans. roy. Soc. S. Aust.* 62. 229-40. 1938.
5. Trumble, H. C. The climatic control of agriculture in South Australia. *Trans. roy. Soc. S. Aust.* 61. 41-62. 1937. maps.
6. New South Wales, Bank Circular. 9. 1. 1939.

2. PLANT INTRODUCTION

A. McTaggart

The first white settlers would have found it next to impossible to live in Australia had they not brought supplies of foodstuffs into the country until crops could be grown. It is an interesting commentary on this ancient continent that our grain, vegetable and fruit crops of commercial importance and the grasses and legumes used in sown pastures in the better rainfall areas are all introductions. Unfortunately, during the same period, several hundreds of weeds, noxious and otherwise, have been inadvertently introduced, while some deliberate introductions have become established as plant pests ; for example, *Homeria collina* and *H. miniata* (Cape tulip) and *Oxalis cernua* (soursob) are both garden escapes first introduced by gardening enthusiasts. Individuals and Governments have been engaged in plant importation since the First Fleet, and to-day they are sporadically, and the C.S.I.R. and State Departments are systematically engaged in plant introduction. The danger of introducing diseases and pests is obvious, and quarantine regulations are promulgated with a view to minimizing the possibility of such introductions. Actually, only C.S.I.R., the State Departments of Agriculture and certain institutions are equipped to conform to quarantine regulations. Introductions by individuals are fraught with danger and the greatest care has to be exercised by all institutions in order to avoid undesirable species.

The ideal way to carry on plant introduction involves seven clearly defined principles which are as follows :

(1) A climatic, soil and vegetational survey to determine the ecological environments in which plants are required to fill particular roles.

(2) The search for such desirable plants, preferably by exploration, in homoclimes of the world.

(3) Imported material to pass through quarantine.

(4) Preliminary testing in strategically placed testing centres to determine their potential value under our conditions.

(5) Multiplication and accumulation of seed stocks or stocks of cuttings, etc., for wider and more detailed trial.

(6) Detailed trials of selected species under normal agricultural practice and comparison with standards. This phase for herbage plants will include yields and grazing tests in suitable seeds mixtures.

(7) The species emerging successfully would then be handed to State Departments and other organizations and individuals for widespread tests.

C.S.I.R. has been unable to undertake a series of surveys of the country by zones, such as has been done elsewhere (South Africa, for example), chiefly because of the cost. Naturally the State Departments of Agriculture have concentrated their efforts in the better rainfall areas, and have tended to use those early introductions which have already demonstrated their value, such as lucerne, the clovers, ryegrasses, *Phalaris*, etc. The Commonwealth organization therefore tended to cater for the areas of lower rainfall, admittedly a far from easy task. Instead of making surveys

on a systematic basis, an attempt has been made, and with some success, to acquire the information by study of reports of expeditions and of exploration and survey parties, by making contacts with Lands and Surveys Departments and so forth. Some data have been accumulated personally, and now that a Section of Agrostology has been established it is hoped to augment data from that source.

As with the first principle so with the second, the exploration of homoclimes abroad has been indirect and of the armchair type. Only by painstaking and voluminous reading of all kinds of floras, books of exploration and particlarly plant exploration, bulletins, pamphlets, etc., covering most of the sixty-odd countries of the world has it been possible to accumulate the present stock of introductions. The C.S.I.R. stock of introductions now totals 6,686, including 1,406 grasses, 1,250 legumes, 72 miscellaneous herbage plants, 2,800 wheats and a further large miscellaneous group including fibre, oil, fruit and other plants. The wheats have mainly come as large collections, but all the others have arrived as individuals.

In the course of the work definite concentration of effort has been made to seek pasture plants for the lower rainfall areas, for the northern subtropical and tropical country, and for use in erosion control in various parts of the continent ; while attention is steadily directed to the requirements of the southern winter rainfall belt.

All introductions are first placed under quarantine because of the responsibility of ascertaining that diseases and pest plants are not among the immigrants. Preliminary testing is undertaken at three centres : Canberra for those apparently suitable for the Mediterranean type of climate, Lawes for subtropical introductions, and Fitzroyvale, just outside Rockhampton, for more tropical types such as are susceptible to frost.

As in most instances only very small supplies of seed are received, it is only possible to make first studies on individual plants or in plants in rows. With the numbers under test it is evident that this is a formidable task, and many difficulties are encountered. For example, it often happens that there is a difference in the ratio of light and dark hours, or in total heat or distribution of rain at our testing station as compared with the original habitat, as a result of which plants will not set seed. Frequently the seed sample is not a pure line and considerable variation between plants occurs. It is necessary to observe and note all such facts and to study the type of growth of plants in a preliminary, rather diagnostic way, in order that some idea may be gained of their possible use, if any. They are also checked taxonomically. All the introductions are recorded in inventories which are mimeographed and supplied to State colleagues and to institutions.

If the introductions are of a special nature, such as fibre plants, tobacco types, oil-producing plants, dates, and so on, they are handed as soon as possible to the officers or institutions desiring them. Selected grasses and legumes are subjected to plot study and to grazing and mowing in order to determine longevity, palatability and productivity. Obviously this cannot be done from the beginning with all or even most of the species, because the demands for space and labour on such a basis would be impossible to meet.

Almost 3,000 lots of seed have been issued to Departments of Agriculture, Agricultural Colleges, pastoral companies, and individuals in all States. In fact, the

accumulation of seed stocks for such issues and for our own testing is in itself a task.

By arrangement, the Department of Agriculture in each State supplied a record of its introductions and the results of tests made on them for the past twenty-five years in order to avoid overlapping of effort. In turn, C.S.I.R. has issued six inventory lists which give the source and a brief description of each introduction. All introductions, by whomsoever made, come within the scope of the Commonwealth Quarantine Act and proper steps must be taken to ensure that diseases and pests are not allowed entry.

In New South Wales both the Agrostology and the Plant Breeding Branches have many plants under test, the material being collected from world-wide sources. The Victorian Department of Agriculture is paying special attention to C.S.I.R. and their own introductions for light soils and low rainfall conditions, the tests being carried out at the Mallee Research Station at Walpeup. *Ehrharta calycina* and the Mulwala strain of *T. subterraneum* are the most promising new species for that country.

In addition to the work in Queensland carried on by the Department of Agriculture and Stock at coastal, intermountain and plains stations such as South Johnstone, Biloela, Roma, etc., the Queensland Acclimatization Society, which issued its 72nd Report for the year ending March 31, 1938, has also tested a number of introductions. Among noteworthy introductions of long standing are, of course, Rhodes grass (*Chloris gayana*) and more recently Molasses grass (*Melinis minutiflora*).

The Department of Agriculture in South Australia tests plant immigrants at Kybybolite, Kingston, Bowmans, Bute and Baroota with rainfall ranging from 24 inches at the first to 12.5 inches at the last-named. Some success has been achieved in establishing *Ehrharta villosa* and *Elymus giganteus* on light drifting areas of 12 to 15 inches annual rainfall. At the Waite Agricultural Research Institute, emphasis is laid on southern Europe and northern Africa as sources of supply. A dryland form of cocksfoot from Morocco and a vigorous strain of strawberry clover originating in Southern Rhodesia have proved highly productive. *Medicago obscura* from Italy is promising as a self-regenerating medic and *Paspalum vaginatum* from South Africa appears to be adapted to saline soils.

In Western Australia the aim is to find pasture plants to suit the south-western area and also, if possible, the drier country, the work being carried out by the Department of Agriculture itself, and in co-operation with C.S.I.R. Plants of outstanding importance, now semi-naturalized, are *Ehrharta calycina* and *Lupinus* spp. Buffel grass (*Cenchrus ciliaris*), accidentally introduced through trade channels and Birdwood grass (*C. biflorus*) have shown marked drought resistance in the Port Hedland and other western areas. *Festuca Mairei* is also regarded as a potentially valuable species for winter-growing areas.

Tasmania is also testing selected species at Cressy, but is concentrating chiefly on obtaining new strains of existing species.

C.S.I.R. tests are in progress in each of the States ; in New South Wales, in co-operation with the Agrostologist's Branch, at Wagga, Orange, Bathurst, Narrabri, Glen Innes, Maitland, and Wollongbar Farm ; in Victoria at Walpeup, Werribee and Burnley ; in Queensland at Toowoomba, St. Lucia, Callide Valley and South Johnstone ; in South Australia at Kybybolite ; in Western Australia at Muresk and in Tasmania at Perth, Devonport and Scottsdale.

From reports received it appears that over fifty introductions are regarded as promising and some are regarded as definitely valuable, while a further fifty species have been selected for more detailed trial. It is not proposed to deal with each of these, but brief reference to one or two may be of interest.

At Canberra a number of valuable introductions for pasture and herbage, both grasses and legumes, are undergoing critical tests. *Bromus arduennensis, Festuca elatior* and *Agropyron cristatum* yield favourably in comparison with *Phalaris tuberosa*, while *Festuca Mairei, Agropyron intermedium* and *Bromus inermis* yield nearly as well. *Phalaris stenoptera, Festuca elatior* and *Agropyron cristatum* are very persistent, while the species of *Bromus* and *Agropyron* are very palatable.

Comparisons are being made between several lines of lucerne (*Medicago sativa*), including some from Turkey, Iraq, Argentine, Bolivia, Persia, Kansas, California, Arizona, and the Hairy and Smooth Peruvian and Calehaqui varieties, while lines of *M. falcata* and *M. coerula*, as well as crosses between *M. sativa* × *M. lupulina* are being subjected to sward tests.

Having shown good yields and persistency in the earlier phases, the following clovers are now being tested in swards, in comparison with *Trifolium repens* as a standard : *Trifolium tumens, T. montanum, T. repens* var. *giganteum, T. johnstoni, T. ambiguum*, and a line of *T. fragiferum*.

Species of definite value for the control of soil erosion under different conditions are *Bromus inermis, Calamagrostis epigeios, Elymus giganteus, E. angustus, E. pseudagropyron, E. multicaulis, Agropyron ramosum, Cynodon transvaalensis* and *Panicum obtusum*.

At Lawes, 60 miles west of Brisbane on heavy black soil, in a semi-tropical climate with annual rainfall of 29 inches, of which 20 inches or 68 per cent falls during the six summer months, tests have been conducted for the past five years. Valuable pasture grasses for south-eastern Queensland are *Brachiaria brizantha* from Kenya, a strain of *Panicum maximum, Urochloa trichopus, Paspalum scrobiculatum, Brachiaria dictyoneura, Digitaria valida* and *D. pentzii* from South Africa and *Eragrostis superba*. Legumes undergoing further test are two lines of *Lespedeza striata* and two of *L. stipulacea* ; the most successful perennial lespedeza is *L. daurica*, while *L. juncea* and *L. sericea* give every indication of being useful winter legumes in this environment. Others giving consistently good growth are *Phaseolus semi-erectus, Crotalaria usaramoensis, Cicer arietinum* and *Alysicarpus rugosus*.

Tests have been in progress for three years at Fitzroyvale, near Rockhampton, some 400 miles north of Brisbane in typical cattle country, where the environment is practically frost-free and tropical with an annual rainfall of 40 inches ; the outstanding legume species for pasture purposes here are : *Stylosanthes guyannensis* from Brazil, a palatable perennial legume that is persistent, drought-resistant and remarkably productive under favourable conditions, and a good source of feed during the dry winter and spring months ; *Arachis prostrata*, a self-regenerating short-lived perennial legume, burying its fruit and apparently a potentially valuble pasture species. Other legumes undergoing further test are *Centrosema pubescens, Pueraria hirsuta, Glycine javanica, Meibomia discolor* and *Arachis nhambiquara*.

The following grasses are outstanding : *Panicum maximum* and varieties, the native *P. antidotale, Urochloa bolbodes, U. mosambicensis, Cenchrus ciliaris, Melinis minutiflora, Brachiaria brizantha, B. decumbens, B. dictyoneura, Chloris gayana* strains, *Andropogon annulatus* and *A. pertusus, Amphilophis glabra* and *Digitaria milanjiana*.

It is evident that, as a result of the efforts of all those participating in plant introduction both in the Commonwealth and States, many potentially useful species of grasses and legumes have been found. It is not to be expected that a high percentage of these will utimately find their way into economic use, because many of the species may not be capable of establishment and growth under the required conditions, or difficulties in seed production may later preclude their successful use in pastures. Nevertheless, if only a few are found which approach *Trifolium subterraneum* or *Phalaris tuberosa* in value, the whole programme will have been eminently justified. In conclusion, the suggestion may be ventured that *Stylosanthes guyannensis* is one such species and there are several grasses of distinct value.

3. PASTURE PLANT BREEDING IN AUSTRALIA

J. R. A. McMillan

As in other branches of agrostological investigation in Australia, pasture plant breeding is undertaken by several different authorities working in one or more States. The C.S.I.R. is working in the Australian Capital Territory, New South Wales, and Queensland ; the Waite Institute in South Australia ; and the Departments of Agriculture of New South Wales, Victoria, South Australia, Queensland and Tasmania in their respective States.

The continent has such a wide range of climatic conditions that it is to be expected that different strains of a species would be required for different districts. Perennial ryegrass and cocksfoot are grown from northern New South Wales with a summer rainfall to southern Tasmania with a winter rainfall. Lucerne is grown from Tasmania to Queensland. It is for this purpose—the production of strains suitable to local conditions—that work with the same species is being undertaken simultaneously at several different stations.

Methods

The methods employed in the production of improved strains of pasture species in Australia differ according to the investigator and to the problem. For self-fertilized species, methods similar to those used for wheat, oats and barley are adopted, but for cross-fertilized species the methods vary from very simple forms of mass selection to comprehensive programmes which envisage the following :

1. Collection of material with particular attention to both eco- and agro-types. As wide a range as possible of ecotypes and strains of the species under investigation is obtained from all available sources both within Australia and overseas. This is obtained primarily by correspondence and therefore cannot be as complete as is desirable. Material is collected also from Australian sources wherever possible and in some cases this has proved most useful, as is well illustrated by Victorian strains of ryegrass from Colac, Clunes and Kyneton, which are more suitable for their respective districts than the Hawkes Bay strains. These strains were selected from fields grown in the areas concerned. Similarly, all the commercial strains of subterranean clover have been obtained from Australian fields.

2. Comparison of the collected material as swards and spaced plants. In some cases these are grown in pure stands, but in others the grasses are grown in association with the recognized legume for the area, and the legumes with the best grass. The material is cut, or grazed by sheep.

3. Selection. This is based first on the phenotype, and then on the genotype as revealed by progeny tests. For seed for the latter the parent may be inbred or crossed or open-pollination may be permitted.

4. Mass inter-pollination of selected plants for seed production.

5. Critical sward tests of new strains compared with the best commercial types, conducted under field conditions of management and grazing.

6. Hybridization. Hybridization is employed in some cases, but generally Australian pasture plant breeders consider that there is ample genetic variation available for selection in most species and that no useful purpose will be served at this stage by undertaking a crossing programme. Some hybridization work which has been done is that of C.S.I.R. on subterranean clover and lucerne, the New South Wales Department of Agriculture on an intergeneric and interspecific crossing programme, and the Waite Institute with lucerne.

7. Incidental investigations. These include studies on pollination, fertility, technique of hybridization and breeding methods.

Species under Investigation

Lucerne—Medicago sativa

Lucerne is becoming increasingly used for grazing purposes in moderate rainfall areas of Australia, both in mixtures and as a pure sward. Up to the present the common hay types have been sown for grazing, but breeders are now attempting to produce other types which would be specially suitable for this purpose. The New South Wales Department of Agriculture has done much work at Bathurst on breeding technique with lucerne, and Dwyer has developed the "close-breeding" method. The C.S.I.R. work has been concentrated at Lawes in Queensland, where methods are also under investigation. High yielding, good grazing types are sought. The best yields from the point of view of quantity and seasonal distribution are obtained from *Medicago sativa*, but it is badly damaged during grazing owing to its high crown. Low crown types are poor in yield. Attempts are being made to breed and select the most desirable combination of crown type and yield. In the same area mortality is high because of flooding or continuous wet weather, and various diseases such as wilts and witches' broom. Better grazing types are being bred at the Waite Institute for South Australian conditions from crosses between common lucernes and a rhizomatous type. Strain comparisons are being undertaken in Victoria. Experiments on problems such as crossing, pollination, seed production, etc., are also in progress.

White Clover—Trifolium repens

New Zealand strains of white clover are used most extensively in Australia, but there is strong evidence to show that better strains for Australian conditions can be produced. In Victoria an irrigation white clover strain which is vigorous, larged leaved and particularly adapted for irrigation, has been produced. The New South Wales Department of Agriculture has selected strains which are showing better spreading habit and persistence, giving a longer growing season. The C.S.I.R. at Moss Vale reports white clover plants which are much superior to the average.

Red Clover—Trifolium pratense

Red clover is under investigation in New South Wales, Victoria and by C.S.I.R. The New South Wales Department of Agriculture has produced strains which are more frost resistant. At Moss Vale, the C.S.I.R. work indicates the existence of

strains which are more persistent and more productive than the commonly used Montgomery Red. In the absence of *Bombus* species the honey bee must be relied upon for pollination, and in this connexion it may be desirable to produce strains with short corolla tubes.

Subterranean Clover—Trifolium subterraneum

Over large areas of southern Australia, *Trifolium subterraneum* is the mainstay legume, but, with its wide range of strains, investigation is necessary to determine the most suitable type for the moisture, temperature and pH conditions obtaining. Strain investigation is being undertaken in each of the southern States and already many types have been isolated for various climatic conditions. Earlier maturing types would enable its range to be extended considerably in the drier areas and such strains are now being sought.

Other Annual Legumes

Subterranean clover is limited in range by rainfall and soil reaction. It cannot be established satisfactorily where the rainfall is less than 20 inches, unless it is practically all winter rainfall, and it is not suitable for alkaline soils. It is for areas such as these that attention has been given to other legumes such as annual medics and annual *Trifolium* species which are widely distributed. The main objection to these is the very large seasonal fluctuation in yield. Preliminary work indicates that *Medicago hispida* var. *denticulata*, *M. tribuloides* and *Trifolium glomeratum* are the most promising.

Perennial Ryegrass—Lolium perenne

Perennial ryegrass is the main grass of pasture mixtures in the southern areas of high rainfall and fertile soil. Most of the seed sown is the Hawkes Bay type from New Zealand, but evidence is available that more suitable strains can be obtained for Australia. With this object in view, most of the Departments of Agriculture, the Waite Institute and C.S.I.R. have undertaken a programme of selection for different districts. The Victorian Department has isolated particularly suitable strains for special areas, for example, Clunes, Kyneton and Colac strains. In South Australia the Waite Institute has produced four strains which are being tested against standard commercial certified strains. Strains selected in New South Wales are showing improvement in crown density, tillering, recovery after grazing and perenniality. The C.S.I.R. work at Moss Vale and that of the Department of Agriculture, Tasmania, is not so far advanced.

Cocksfoot—Dactylis glomerata

Cocksfoot is being investigated under the same conditions as perennial ryegrass and for the same purposes. A Victorian strain has been produced which is more suitable for the local conditions. In New South Wales selections exhibit improved density, tillering, recovery after grazing and perenniality. At Canberra, a new strain of considerable promise shows good drought resistance, summer growth and winter greenness.

Phalaris tuberosa

Phalaris tuberosa is now recognized as one of the most valuable grasses for moderate rainfall areas in southern Australia. It has been subjected to selection in South Australia at the Waite Institute, New South Wales and Victoria and in each case improved strains have been obtained. The Waite Institute strains show improvement from the point of view of density of tillering and are finer in the stems and leaves. Strains developed in New South Wales are improved in earliness of spring growth, length of growing season, vigour and bulk, leafiness, frost resistance and in some cases seed production. *Phalaris* has possibilities in Queensland for production of winter feed. This is being investigated by C.S.I.R. at Lawes, where many strains and plants are being tested. The first objective in these experiments is to obtain types which are persistent under southern Queensland conditions.

Rhodes Grass—Chloris gayana

Rhodes grass has been grown in Queensland for some thirty years and now is the chief sown pasture grass in the dairying and stock fattening sub-coastal country of southern and central Queensland. An examination of the Rhodes grass strains available shows a very wide range of ecotype, and selection is being undertaken by C.S.I.R. at Lawes. Improvement is directed towards the production of leaf and stem rather than flower-heads in the early part of the season, increased length of growing season and winter growth, frost resistance and improved quality including palatability. A strain obtained from Kenya appears most promising and is being mutiplied for extensive testing.

Wallaby Grasses—Danthonia Species

Danthonia spp. are, or were, dominant over most of southern Australia and provide most of the grazing material for sheep in 20-inch rainfall country. Wallaby grasses are persistent, can withstand cold and drought, develop new leafage rapidly after rain in hot weather, and can grow in soils of lower fertility. It may be possible to increase productivity by selection and this is being attempted at Canberra. The awns and hairs on the " seed " make it difficult to harvest and sow, and hence the possible reduction of this handicap is in mind.

Wimmera Ryegrass—Lolium multiflorum

Wimmera ryegrass has been improved by selection both in Victoria and New South Wales, and improved strains have been distributed.

Prairie Grass—Bromus Species

At the Waite Institute improvements in yield and resistance to smut have been sought in prairie grass, and improved strains will be released shortly.

Native Species

In addition to *Danthonia*, other native species are being investigated. Mitchell grasses (*Astrebla* spp.), being examined by C.S.I.R. at Lawes, show a wide range

of ecotype which indicates possibilities of obtaining improved types. In New South Wales various saltbushes are under observation.

Other Species

Other species being investigated are Hooker's fescue (*Festuca Hookeriana*), *Paspalum dilatatum* for ergot resistance, Sudan grass, and giant panic (*Panicum antidotale*) in New South Wales; and strawberry clover (*Trifolium fragiferum*) at the Waite Institute and in Victoria.

Related Problems

In many cases problems associated with flowering, fertilization, pollination, seed setting, etc., are being undertaken simultaneously with the breeding work. In New South Wales a programme of intergeneric and interspecific crossing is being undertaken between *Avena*, *Hordeum*, *Secale*, *Phalaris*, *Agropyron*, *Festuca*, *Poa*, *Trifolium*, *Medicago* spp., etc., and cultivated crop plants.

4. THE NATURAL SEMI-ARID PASTURES OF NORTHERN AUSTRALIA

R. Roe

The natural pastures of Australia, using the term "natural pastures" in its broadest sense to include all edible native species, form an important source of wealth. Except in the southern portion of the continent, where the winter incidence of rainfall and its relatively low variability render the annual precipitation more effective, the outer limit of sown pastures may be taken at the 25-inch isohyet. On the more arid side of this division, recourse to native species for fodder must be made. This area comprises over two million square miles, 79 per cent of the continent, although a portion of the very arid interior with an annual precipitation of less than 5 inches is useless for pastoral purposes. Most of the wool, worth fifty-five million pounds, and cattle, grown for beef, worth one and a half million pounds (average for 1933-34 to 1937-38), exported from Australia comes from this area.

North of a line drawn from Port Hedland on the north-west coast to Grafton in the east, the rainfall is predominantly summer in incidence. It is characterized also by its unreliability, the variability being of the order of 30 to 35 per cent. At far northern stations, the months of June to September inclusive are practically without rain, but the winter rains increase progressively towards the south, particularly in eastern Australia, until, at the latitude of Canberra, winter and summer rainfalls are approximately equal. In the north, with its summer rains, conditions are suitable for the production of true grassland.

In the east, where the soils, although in some cases alluvial, are largely volcanic and/or calcareous in origin, the Mitchell grass (*Astrebla* spp.) and bluegrass (*Dichan-*

thium sericeum) associations are developed. In the north of Western Australia, however, within the 25-inch isohyet, the soils are largely sandstone with occasional outcrops of conglomerates, and here the grassland is composed of a miscellany of species. South of the Mitchell grasslands, in the State of New South Wales, where the effect of winter rains becomes evident, wallaby grasses (*Danthonia* spp.) become dominant in the grassland.

A large area of Queensland, between the 20 and 25-inch isohyets and south of latitude 20°S. is broadly described as acacia scrub, of which brigalow (*Acacia harpophylla*) is the most characteristic species. Towards the south-west, as an expression of the more arid conditions, there is the mulga scrub (*Acacia aneura*) formation, and in the extreme south-west corner and extending into the arid interior is the spinifex (*Triodia* spp.). This country verges on desert.

West of the 15-inch isohyet in New South Wales and extending across most of South Australia north of the 10-inch isohyet is a belt of saltbush (*Atriplex* spp.), a shrub-steppe formation, interspersed with small areas of mulga. The mulga is more extensively developed in South Australia than in New South Wales, but as the rainfall in this area is chiefly of winter incidence, it will not be considered further.

The major pasture associations of semi-arid northern Australia may, therefore, be broadly classified into four main groups :—

1. Grassland—in eastern Australia on volcanic and calcareous soils.
2. Grassland—in northern and western Australia on sandstones.
3. Scrubs—dominated by *Acacia* spp.
4. Miscellaneous associations, the chief of which are spinifex, chenopodiaceous communities other than *Atriplex*, communities of the channel country, etc.

Grassland in Eastern Australia on volcanic and calcareous soils

This vast association, comprised largely of Mitchell grass (*Astrebla* spp.), which is dominant, and bluegrass (*Dichanthium sericeum*), occurs as an open, rolling, treeless grassland or as savannah. Its main development stretches from near the Gulf of Carpentaria in a south-easterly direction almost to Charleville. A small area occurs in the vicinity of Cunnamulla, with a further development eastwards on the Darling Downs and southwards into New South Wales. The Barkly Tableland in the Northern Territory, and another area near Wave Hill, are typical of this association, and it is further represented in scattered small areas in the south Kimberley district in Western Australia. This distribution of the Mitchell grass downs was described by McTaggart (**10**). In Western Queensland, towards the South Australian border, is a further extensive area of Mitchell grass country, differentiated by Blake (**4**) as " The Gravelly Downs Group ". There the soil, " a yellowish brown to light chestnut clay silt or clay loam (rarely somewhat sandy), is invariably associated with gidgee gravel, and is more compact than that of typical ashy downs ". The species on this type also differ somewhat from the typical Mitchell grass association.

Four species of *Astrebla* are recognized (**9**) ; although they may and do occur together in the same area, each tends to be restricted as a dominant to a particular area. In the north and east, *Astrebla lappacea* (curly Mitchell grass) and *A. elymoides*

(hoop Mitchell grass) are co-dominants, with *A. squarrosa* (bull or wheat-eared Mitchell grass) in the more favourably watered situations. *A. pectinata* (barley Mitchell grass) is dominant over most of the Gravelly Downs, although the curly Mitchell may also be present.

Astrebla squarrosa is a much more robust species than the others. It has a large and heavy curled inflorescence, often growing to a height of 4 to 6 feet. It is generally considered the least desirable of the four. *A. pectinata* usually grows about 2 feet high. It is somewhat glaucous, and the seed-head compact, often being enclosed on one side in the sheath. *A. elymoides* is the smallest of the species. Its leaves are glaucous and dry early. The inflorescence is long and slender, on an extended flexuose culm, which, bending over, gives the plant its common name. *A. lappacea* is rather intermediate in habit between the latter two, but has a larger seed-head. A pronounced tendency to curl on the part of the older leaves, a characteristic to be found with all species, but more so with *A. lappacea*, is responsible for the common name.

Although these differences exist as between species, they have much in common. All the Mitchell grasses are perennial tussocky species which flower freely, but sometimes fail to set seed. Blake (**4**) states that the seed germinates readily under a variety of conditions. The tussocks vary in size, a well-developed one being up to 12 inches in diameter, and with upwards of fifty flowering culms. A dense stand of Mitchell grass may have closely spaced tussocks, but they never form a complete cover or sod ; there may be from 4 to 6 feet between individual plants in an association dominated by Mitchell grass.

Francis (**7**) makes some interesting observations on the structure of the tussock which help to explain the persistence of the Mitchell grasses under stocking. The stems originate from a hardened, creeping rootstock beneath the soil surface. This is a robust structure from 0.125 to 0.5 inch in diameter and enclosed in sheathing scales. The stems are fibrous and the leaves also are firm in texture and lack the succulence exhibited by many grasses.

Although in these grassland associations the Mitchell grass is dominant, other grasses of a somewhat similar habit are frequently found in varying degrees of abundance. Bluegrass (*Dichanthium sericeum*), which is much favoured by pastoralists, occurs towards the better rainfall areas, and in some localities assumes dominance. Brown-top (*Eulalia fulva*) and never-fail (*Eragrostis setifolia*) are also important components of the Mitchell grasslands. All these species have a tussocky habit, and the open nature of the cover they provide makes possible the presence of numerous other grasses, short-lived perennial herbaceous species and ephemerals.

Chief among the miscellaneous grasses are *Iseilema* spp. (Flinders grasses), *Panicum Whitei*, *P. decompositum*, *P. queenslandicum*, *Paspalidium globoideum*, *Eriochloa* spp. (summer grasses), *Eragrostis leptocarpa*, *E. parviflora*, *Chloris divaricata* and *C. truncata* (star grasses), *Aristida latifolia* (feather-top), *A. leptopoda*, *Enneapogon avenaceus*, *E. Lindleyanus*, *E. nigricans*, *Dactyloctenium radulans* (button grass), *Sporobolus australasicus*, *S. Caroli* and *S. actinocladus*. Of these, the Flinders grasses, the systematics of which have been worked out by Blake (**3**), are of importance on

account of the palatable and nutritious dry feed provided, particularly during relatively rain-free winters.

The families chiefly represented among the short-lived perennial herbaceous species and ephemerals which occur on these grasslands are the Chenopodiaceae, Compositae, Malvaceae and Leguminosae. The most important chenopods are *Atriplex* spp. (saltbushes and salt weeds), *Salsola kali* (roly-poly), *Bassia* spp. (the various kinds of burr), *Threlkeldia proceriflora* and *Kochia* and *Rhagodia* spp. The composites include various species of *Calotis*, *Brachycome* and *Helipterum*; the Malvaceae, species of *Abutilon*, *Sida*, *Hibiscus* and *Malvastrum spicatum*. The species of the family Leguminosae do not add any great bulk to the forage on these grasslands, but their value as a source of protein and in maintaining the nitrogen balance in a cover almost exclusively gramineous is probably very high. The most important legumes are *Sesbania Benthamiana*, *Rhynchosia minima*, *Crotalaria dissitiflora*, *Glycine falcata*, *Psoralea graveolens*, *P. cinerea*, *Indigofera* spp., *Aeschynomene indica*, *Neptunia* spp., and *Cassia* spp. Miscellaneous species which assume some importance are *Trianthema crystallina*, *T. decandra*, *Portulaca* spp. (pigweed), *Amarantus Mitchelli*, *Daucus brachiatus*, *Plantago varia* (lamb's tongue), *Solanum esuriale* (wild tomato), and *Boerhaavia diffusa* (tahvine).

There is a change in the species with the southern extension of the open grasslands into New South Wales. Species of *Stipa* assume dominance, and further south, with a change of soil types and increasing winter rainfall, there is a merging into the *Danthonia*-dominant association. Species of *Medicago* and *Erodium* are important herbage constituents of these more southern grasslands.

The miscellaneous components of the northern grasslands mentioned above show considerable variability from one locality to another, their presence or absence or vigour reflecting small local changes in the habitat, short climatic fluctuations, and method of stocking in previous years. For this reason, Blake (**4**) has suggested the application of the term " indicator communities " to this short-lived vegetation, and the marked changes that are effected in their composition by various stocking practices commends the adoption of this term and the development of the use of the indicator communities as a guide to the optimum utilization of the pasturage.

Grassland in Northern and Western Australia on sandstones

The soils of this group are generally inferior and derived from variable rock formations. The grass species, too, are inferior. In the Northern Territory, McTaggart (**10**) records the following species :—*Heteropogon contortus* (bunch spear grass), *Triodia* spp. (spinifex), *Andropogon hygrometrica*, *Aristida calycina*, *A. Browniana*, *Perotis rara*, etc. Throughout this variable zone, but occurring on isolated areas of better soils, are recorded *Eulalia fulva*, *Astrebla pectinata*, *Pappophorum nigricans*, *Dichanthium sericeum*, *Chrysopogon pallidus*, *Cymbopogon procerus*, *Bothriochloa intermedia*, *Sorghum intrans*, *Setaria macrostachya*, *Sporobolus pulchellus*, and, on the still more fertile, better-watered areas, *Iseilema membranacea*, *Eriachne obtusa*, *Themeda australis* and *Cynodon convergens*. Not all of these are good pasture grasses, but some do provide fair grazing.

In Western Australia, the grassland zone in the north is restricted to an area having a somewhat lower rainfall than that just considered in the Northern Territory. It is, however, very extensive and includes most of the country from Onslow to Broome for an average distance of about two hundred miles inland. It then leaves the coast and extends eastwards into the Northern Territory as a zone about 150 miles wide, including a portion of the Fitzroy and South Kimberley districts. The whole of this area is characterized by a very unreliable rainfall, and towards its southern extremity the variability may be of the order of 60 per cent. Consequently, any perennial elements in the grass cover must show considerable drought resistance. The tussocky species of *Eragrostis*, notably *E. eriopoda*, and of *Eriachne* are the chief components. In the more favourable situations, depressions, etc., where moisture is retained for longer periods, taller perennials such as *Sorghum* and *Andropogon* are found, and additional genera include *Eleusine*, *Iseilema*, *Chrysopogon*, *Themeda* and *Astrebla*. As in many other parts of Australia, favourable rains are followed by a prolific growth of annual grasses and herbaceous species.

Those portions of northern Western Australia where the grasslands exist as open treeless plains are mostly restricted to areas with an annual rainfall of up to 45 inches. The formations considered above, where the rainfall is less than 25 inches, are mostly sclerophyllous woodlands, *Eucalyptus*, *Acacia* and *Hakea* being the chief tree species. Top feed (edible trees and shrubs) is plentiful, the most important species being *Acacia suberosa*, *A. Farnesiana*, *Dichrostachys spicata* and *Heterodendron oleifolium*. Gardner (**8**) has described one association in this sclerophyllous woodland where the dominant species is *Acacia tumida*, the Pindan wattle. It occupies the country to the south and east of Broome.

Scrubs—dominated by Acacia species

These cover an extensive area in Australia, and are developed on a variety of soil types. The formation is dominated by a stunted tree species which may be up to 15 or 20 feet high. The density of the dominants is such that a closed canopy is generally formed, and the ground cover is sparse. Following clearing, however, a good growth of grass or more often herbaceous species provides excellent pasturage. Many of the trees serve as excellent top feed and provide a useful drought reserve.

In the Northern Territory, to the west and south of the Barkly Tableland and extending southwards into central Australia, is an extensive development of acacia scrub, gidgee (*Acacia Cambagei*) and mulga (*A. aneura*) being the dominants. Still further south this area merges into the sandhill country of the arid centre, where spinifex (*Triodia pungens*) is the principal species.

The brigalow (*Acacia harpophylla*) scrub in Queensland is an extensive area, the eastern and northern limits of which enter the higher rainfall zones and may, therefore, be developed by the use of sown pastures. In the south and west, however, the native species must be relied upon for the provision of fodder; following the killing of the trees, generally by ringbarking, a good growth of miscellaneous grasses, chiefly *Eragrostis*, *Chloris*, *Eriochloa*, *Aristida*, and *Paspalidium*, is produced. This particular scrub area, when developed, will provide a valuable pastoral unit.

In Western Australia the broad transition zone between definite summer and winter rainfall regions is occupied by the mulga. The mulga scrub stretches from the Ashburton River in the north to Shark Bay in the south, across the State in a broad zone approximately 300 miles in width. Its continuation through northern South Australia to south-western Queensland is rather broken and it exists as scattered areas among the saltbush (*Atriplex* spp.).

The term mulga is given to numerous species of *Acacia*, but most commonly to *A. aneura*. Among numerous other acacias known by distinctive common names, and which assume local prominence in various situations are gidgee (*A. Cambagei*), lancewood (*A. Shirleyi*), red mulga or minaritchie (*A. Cyperophylla*), bogada bush (*A. liniphylla*), snake wood (*A. Grasbyi*), etc.

Towards the most arid portions of the acacia scrubs, the trees become dwarfed and less closely spaced, permitting development of a ground flora which is, however, harsh and relatively unpalatable; the stock-carrying capacity is therefore light, probably about one sheep to twenty acres. Typical harsh grasses are *Triodia* spp. (spinifex), *Triraphis*, *Amphibromus* and *Stipa*, while useful plants include *Trichinium*, *Atriplex* (saltbushes) and *Kochia* (bluebushes). Good rains are followed by a prolific growth of ephemeral species, which are, however, too short-lived to affect the carrying capacity materially.

Miscellaneous Associations

The lower courses of some of the larger inland rivers, where they traverse particularly level country, may be some miles wide and particularly liable to flooding. This channel country produces a most luxuriant cover of vegetation following floods, and in Western Queensland, the lower courses of the Bulloo, Wilson, Cooper, Diamentina and Mulligan Rivers are rated very high as fattening country. Blake (**4**) has enumerated the chief species in the communities of the channel country as follows:—Two grasses are characteristic and are highly esteemed. These are the so-called "Sorghum", *Echinochloa Turneriana*, an erect, succulent annual several feet high, and a heavy producer of grain, and the shorter "pepper grass", *Panicum Whitei*. In the rich herbage the outstanding plants are *Trigonella sauvissima*, *Blennodia canescens*, *B. nasturtioides* and other species, *Lepidium rotundum* and species, *Craspedia chrysantha* (yellow-top), *Helipterum* spp., *Senecio Gregorii*, *Calocephalus* sp., *Gnephosis eriocarpa*, *Goodenia* spp., various Scrophulariaceae, *Marsilea Drummondii* (nardoo), and occasional species of *Bassia* and *Atriplex*.

Although the highly rated saltbush (*Atriplex vesicarium*) country of South Australia does not come within the purview of a discussion on the natural pastures of northern Australia, there are other communities dominated by various Chenopodiaceae which are of considerable importance. In the south-west of Queensland occurs a shrub-steppe formation, over the whole of which the sole perennial vegetation is *Kochia planifolia*. Two types of saltbush communities (*Atriplex nummularia* and *A. vesicarium*) occur, but these are of limited extent. Many short-lived chenopods of the genera *Salsola*, *Atriplex*, *Bassia*, *Kochia* and *Threlkeldia* are important forage plants in many areas, while in others indiscriminate stocking has led to the

disappearance of valuable grass species and the intrusion on a large scale of unpalatable herbaceous species which considerably reduce the value of the land as pasturage. *Bassia Birchii*, which has been discussed by Blake (**4**), is one such native species which has over-run large areas in Queensland.

Over a great part of the centre of the continent, chiefly on desert sandhill country, sandstone and quartzite formations, occurs the "spinifex" (*Triodia*) formation. This area receives less than 10 inches rain per annum, and has necessarily a low carrying capacity. *Triodia* forms communities with an exceedingly xerophytic appearance. They are generally treeless, but gnarled and crooked, stunted trees or shrubs, particularly species of *Acacia*, *Hakea* and *Eucalyptus* (in mallee* form), may be present. The plants form dense tussocks which may be up to six feet in diameter, and four feet in height. Fresh growth and branching take place around the periphery of the tussocks, which after a time may assume an annular appearance, the centres having died. The tussocks are spiny because of the spreading, hard, rigid, convolute leaves, and stock are dependent upon fresh green shoots for feed. Burning stimulates the production of these fresh green shoots, and as all species are readily inflammable, even when green, burning of the spinifex should be a regular practice. The flowering stalks, which are often three feet high, are very numerous and the grain formed is an excellent feed for cattle and horses. The spinifex normally supports very little other vegetation, although after good rains, which are, however, quite rare, there may be a sprinkling of unimportant grasses, and such herbage species as parakeelia (*Calandrinia* spp.) and pigweed (*Portulaca oleracea*).

Among the natural pasture zones which have been considered, the Mitchell grass areas probably take pride of place, and Mitchell grass, as a forage species, is rated rather highly both in the scientific literature and in the lay mind. It is true that Mitchell grass pastures carry large numbers of sheep, but the extent to which they are supported by the dominants of the association is questionable. The *Astrebla* species are not readily eaten while green, and when dry are fibrous, of low nutritive value, and liable to leaching and "blackening" by winter showers. As the result of an investigation at "Elderslie", in Central Queensland, on the yield and chemical composition of natural Mitchell grass pasture during a twelve months' period, Davies, Scott and Kennedy (**6**) showed that the yield of protein and phosphorus decreased markedly from a peak in January to a very low level in September. There was no such fluctuation in the calcium content, but this was at no time very high. The following table shows selected data from the analyses of natural pasture at "Elderslie" station, near Winton, in 1935-36.

The nutritive value of the herbage at the February, April and September harvests respectively was given as approximately 1 : 7, 1 : 9, and 1 : 33, so that even at its best the ratio was probably too narrow for optimum development, and stock must have suffered some nutritional distress.

*A stunted habit, confined to the genus *Eucalyptus*, in which the tree is many-stemmed, the stems rising from a shortened, gnarled, trunk-like structure, the ligno-tuber, situated at or slightly below ground-level. The mallee may vary from six to twenty feet in height.

Date	Crude protein	Phosphorus	Calcium
21.1.36	17.3	0.206	0.31
18.2.36	14.9	0.178	0.30
10.3.36	9.9	0.153	0.39
8.4.36	9.1	0.126	0.30
6.5.36	5.0	0.100	0.29
2.6.36	4.4	0.071	0.28
30.7.36	3.6	0.050	0.29
25.8.36	3.2	0.048	0.33
23.9.36	3.2	0.049	0.32

In this work, analyses were made of " Mitchell grass pasture ", which included, in addition to *Astrebla* spp., annual grasses and miscellaneous herbage; a comparison of the chemical composition of the components of the pasture is thus not possible. This is unfortunate, and investigations to discover the relative value, from a nutritional viewpoint, of the various species comprising the pasture in these regions are urgently needed. There are many indications that Mitchell grass alone falls far short of providing adequate forage for the grazing animal, and that the miscellaneous species are of great importance. In Western Australia (**1**) analyses showed that the protein content of *Astrebla pectinata* during the winter and summer months was 3.5 to 4.4 per cent and 8.9 per cent respectively; Marston (**11**) has described the habits of merino sheep feeding on grassland in Central Queensland and their preference for small miscellaneous species, such as *Glycine tomentosa*, to the abundant grass available.

One of the most urgent needs in the direction of research into the semi-arid pastures of Australia to-day is an intensive study of the floristic relationships of the pastoral country, which will supply the fundamental principles needed for an understanding of the food supply of the grazing animal, and for a scientific utilization of the pasture. Such studies, conducted in conjunction with carefully planned and controlled grazing trials, will do much to solve such problems of management as the maintenance of production of the pasture, the prevention of inedible native species such as *Bassia Birchii* becoming prevalent or dominant, drought insurance by fodder conservation, prevention of brigalow suckering, etc. Recent recommendations along these lines have been made (**5**), and their adoption and the initiation of a large-scale research programme to investigate the problems enumerated above are vitally necessary to safeguard a national asset—the natural grasslands of Australia.

References

1. Beck, A. B., and Underwood, E. J. The composition of some grasses from Turee Creek Station of the north-west pastoral area of Western Australia. *J. Dept. Agric. W. Aust.* 15. 55-60. 1938.
2. Blake, S. T. Notes on some pasture problems of western Queensland. *Proc. Qroy. Soc. Qd.* 1935. 47. 89-91. 1936.
3. Blake, S. T. The genus *Iseilema* in Queensland. *Proc. roy. Soc. Qd.* 1937. 49. 82-94. 1938. pls.
4. Blake, S. T. The plant communities of western Queensland and their relationships, with special reference to the grazing industry. *Proc. roy. Soc. Qd.* 1937. 49. 156-204. 1938. pls. maps.
5. Davies, J. G. Report of survey of pastoral areas in Southern Queensland. *Coun. Sci. Ind. Res. Aust.* (Limited circulation—mimeo.) Melbourne, 1939.
6. Davies, J. G., Scott, A. E., and Kennedy, J. F. The yield and composition of a Mitchell grass pasture for a period of twelve months. *J. Coun. sci. industr. Res. Aust.* 11. 127-39. 1938.
7. Francis, W. D., and Everist, S. L. Inland pastures. Pt. 1. Mitchell grasses in the Warrego district. Pt. 2. Response during 1934 season of Mitchell and other grasses in western and central Queensland. *Qd. agric. J.* 43. 268-81, and 374-87. 1935. [Pt. 1 by W. D. Francis. Pt. 2 compiled from reports received by S. L. Everist. Foreword by C. T. White.]
8. Gardner, C. A. Botanical notes. Kimberley Division of Western Australia. Forests Department Bull. 32. 1932.
9. Hubbard, C. E. The genus *Astrebla* or Mitchell grasses. *Kew Bull.* 1928. p. 257.
10. McTaggart, A. A survey of the pastures of Australia. Embodying ecological information and discussions explanatory of the accompanying pasture map of the Commonwealth. Coun. Sci. Ind. Res. Aust. Bull. 99. Melbourne, 1936. pp. 71.
11. Marston, H. R. Studies in the supplementary feeding of Merino sheep for wool production. —I. Coun. Sci. industr. Res. Aust. Bull. 61. 1932.

5. THE SOUTHERN PASTURES OF AUSTRALIA

R. M. Moore

The majority of the sheep in Australia are raised on the natural pastures of the southern, and especially the south-eastern States. New South Wales, for example, carries nearly half the sheep in Australia. These temperate pastures form the natural basis of the wool and meat industries, and are, therefore, the main source of Australia's national wealth.

Danthonia-Stipa grassland

By far the most important of the southern grazing lands is the *Danthonia-Stipa* grassland, which occurs as large areas of savannah and savannah woodland on the tablelands and western slopes of New South Wales. This association extends northward through northern, central and south-western Victoria to south-eastern South Australia. The greater proportion of the sheep in Australia is carried on this grass-

land, which is especially noted for the production of fine and super-fine wools. The western fringe of this area includes the wheat belt. Most of the fat lambs exported from Australia are produced either on natural or improved pastures of this grassland. Commonly known as *Danthonia* grassland, it is roughly bounded on the east and west by the 25 and 15-inch rainfall isohyets. The northern extension is limited approximately by the 30° parallel of south latitude, while in the south it extends as far as 38° south latitude.

The rainfall is fairly uniform, with a tendency to winter predominance in the southernmost section. It is also reliable, having an average variation from the normal of less than 20 per cent.

Like most of the indigenous vegetation of Australia, the *Danthonia* grassland is naturally poor in herbaceous legumes. It has, however, been invaded by numerous exotic clovers and medics of Mediterranean origin. These are mainly annuals and have become quasi-indigenous, so that the southern grasslands have not the same paucity of legumes so characteristic of the northern subtropical pastures. *Medicago denticulata* (burr medic) and *Trifolium glomeratum* (clustered clover) are the most widespread, while *Medicago minima* (woolly burr medic), *M. arabica* (spotted medic), *M. lupulina* (black medic), *Trifolium arvense* (hare's foot trefoil), *T. procumbens* (hop clover) and *T. tomentosum* (woolly clover) are very common in certain localities. These legumes have a short growing season, but are heavy seeders. The pods or " burrs " of many form a highly nutritious and concentrated foodstuff during the summer. Some of the medics, especially burr medic and woolly burr medic, have spiny pods which are objectionable in wool.

Danthonia, of which there are about thirteen species in Australia, is one of the most important genera of indigenous grasses. The plants are fine-leaved, tussocky, perennial grasses with a wide distribution in southern Australia. The full taxonomic position of the group is not yet clear. *D. semiannularis*, *D. penicillata* and *D. carphoides* are the most important and useful species. Although they reach their greatest development and concentration in the type of grassland under review, *Danthonia* species also occur to a lesser extent in coastal and arid regions.

Usually *Danthonia* is found associated with *Stipa* species in regions of pure grassland or scattered sclerophyllous trees (*Eucalyptus* spp.). These two genera are the dominant perennial grasses over a large portion of the pastoral lands of temperate Australia. Of the two genera, *Danthonia*, commonly called wallaby or white-top grass, is the more valuable. Wallaby grasses are drought-resistant, palatable, persistent under grazing, will grow under conditions of low soil fertility and persist in spite of severe frosts.

The *Stipa* species (spear or corkscrew grasses) of the temperate grasslands are similar in form and habit to the *Danthonia* species, but the leaves are much harsher. At maturity they are very coarse and the fine-pointed fruits cause injury to the eyes and mouth-parts of sheep. The proportion of *Danthonia* to *Stipa* decreases as conditions become more arid and also where overstocking is practised. The number of grasses and herbs in this type of grassland is very large, and varies with locality and rainfall.

On the New England plateau (3,000 feet), in northern New South Wales, *Bothriochloa decipiens* (red grass), an inferior species, is co-dominant with *Danthonia* spp., while *Stipa* spp., *Aristida* spp. (wire-grass), *Poa caespitosa* (tussock grass) and *Chloris* spp. (windmill grasses) are sub-dominants. *Dichanthium sericeum* (Queensland bluegrass), *Stipa* spp. and *Danthonia* spp. are dominant in the drier north-western section of New South Wales, while *Chloris* spp. and *Themeda australis* (Kangaroo grass) are sub-dominants. On the highlands of central and southern New South Wales (2,000 feet), *Danthonia* spp., *Stipa variabilis*, and *Themeda australis* are the most common, while *Poa caespitosa*, *Pappophorum nigricans* (black heads grass), *Panicum effusum* (effuse panic), *Aristida* spp., *Agropyron scabrum* (wheat grass), *Chloris truncata* (star grass), *Microlaena stipoides* (meadow rice grass), *Bothriochloa decipiens* and *Eragrostis* spp. (love grasses) are prevalent and sometimes achieve dominance in localized areas. Such species as *Chloris truncata*, *Panicum effusum* and *Eragrostis Brownii* grow mainly during the summer and are very useful in maintaining continuity in the feeding of grazing sheep. On the very high country (over 3,000 feet), *Poa caespitosa*, which is a smaller and more suitable sheep grass under such conditions, is often the main pasture constituent. *Stipa* spp., *Chloris* spp., *Panicum decompositum* (Australian millet), and *Danthonia* spp. are some of the principal grasses of the drier western section. *Aristida* spp., *Digitaria divaricatissima* (umbrella grass), *Eriochloa* spp. (early spring grasses), *Eulalia fulva* (sugar grass), *Paspalidium jubiflorum* (Warrego summer grass) and *Eragrostis* spp. are sub-dominants. The exotic legumes mentioned previously are very important in these areas, as are also *Hordeum murinum* (barley grass), *Erodium* spp. (crowsfoot) and other herbs.

Further south in Victoria, the *Danthonia* grassland extends southward and westward, embracing a large area of that State. Here *Danthonia* spp. are generally dominant, and *Stipa* spp. sub-dominant, but certain other grasses become important in localized areas, notably *Poa caespitosa* and *Themeda australis*. Annual exotic legumes and grasses are widespread as in other sections of the savannah. The Victorian grassland extends into South Australia, but occupies a relatively small area of that State.

The carrying capacity of the *Danthonia* grassland varies greatly, but it is generally considered to be two sheep per acre. The average would be considerably less, but, except on over-grazed and eroded country, it is seldom less than a sheep to two acres on the moderate rainfall sections. On the more arid fringe the carrying capacity diminishes with increasing aridity. *Themeda australis* disappears quite rapidly under grazing, but if sheep are excluded it will gradually become re-established. Doubtless it was a much more dominant species before the advent of the grazier. *Danthonia* will withstand heavy grazing, but under prolonged over-grazing tends to become replaced by the less palatable *Stipa* and *Aristida* spp.

Davies and Sim (**6**), at the Waite Institute, found that the highest yield of dry matter from a *Danthonia*-dominant pasture was obtained by allowing the herbage to reach maturity. However, cuts taken three times during the season (every 7 weeks) yielded nearly 94 per cent of the yield obtained from one cut, and the her-

bage produced was of higher nutritive value and lower fibre content than the mature herbage. Fortnightly cuts on *Danthonia penicillata* reduced the total yield of dry matter from 183.78 lb. per acre (single cut) to 12.85 lb. per acre.

Herbs such as *Vittadinia australis*, *Erodium* spp., *Calotis lappulacea*, *Acaena* spp., *Malva* spp., *Plantago* spp., *Bulbine bulbosa*, *Wahlenbergia gracilis* and *Pimelia* sp. are widespread over the grasslands. Annual exotic grasses, such as *Vulpia bromoides* (silver grass), *Hordeum murinum* (barley grass), *Aira caryophyllea* (hair grass), and *Briza minor* (shivery grass) are common, especially the first two named. *H. murinum* possesses sharp pointed fruits which frequently cause injury to the eyes and mouth-parts of grazing animals.

Hordeum murinum covers extensive areas in both the moderately wet and semi-arid sections of the temperate grassland. It is very prevalent on stocked land, and provides valuable winter pasturage for lambing ewes in the wheat belt, carrying as many as three to four sheep per acre for a short period. On the Tablelands it grows rapidly in the spring, and matures very soon. It is highly nutritious before heading, but, as mentioned above, its abundant awned fruits are a danger to stock and a disadvantage in wool. However, in spite of the great disadvantages of their spiny fruits, burr medic and barley grass are extremely important plants to the grazier in semi-arid districts.

Much of the *Danthonia* grassland contains an admixture of summer and winter-growing grasses, and this fact has, no doubt, had much to do with the high quality of the wool produced on the Tableland districts. On the extreme southern section, where the rainfall becomes more strictly confined to the winter months, these species tend to disappear, and much of the summer feeding is obtained from dry grass and legume " burrs ".

Higher rainfall areas

On the higher rainfall areas, 18 to 25 inches per annum, particularly on the Tablelands of New South Wales, in Victoria and South Australia, fairly large areas are being sown to subterranean clover (*Trifolium subterraneum*) and to such grasses as *Phalaris tuberosa*, perennial ryegrass (*Lolium perenne*) and cocksfoot (*Dactylis glomerata*). The last two species are usually sown on land receiving not less than 25 inches of rainfall per annum, while subterranean clover is sown on drier areas, especially in regions where most of the rain falls during the winter, as in South Australia. On the more northern section of the grassland (New England), *Phalaris tuberosa* and lucerne (*Medicago sativa*) are extensively sown, while, in the more arid regions, lucerne is sown at the rate of about 1 to 3 lb. per acre, and is utilized solely for grazing purposes. The annual Wimmera ryegrass is also sown in the drier regions.

Pasture improvement

A good deal of pasture improvement is being carried out in the temperate grassland zone. As mentioned above, areas are being ploughed and exotic species sown. Where the *Danthonia* sward is good, subterranean clover is often incorporated into the pasture by surface cultivation methods (that is, cultivating to the depth of 2 to

3 inches with a narrow rigid tine implement). Large areas of natural pasture are being top-dressed with superphosphate, which has the effect of stimulating the growth of the exotic legumes, for example, *Trifolium glomeratum*, etc., and thereby increasing the carrying capacity of the sward.

At the Waite Institute, South Australia, where the rainfall is 24 inches per annum (75 per cent winter incidence), an annual top-dressing of 2 cwt. superphosphate increased the yield of legumes fifteen times and that of *Danthonia* by 62 per cent. However, research both in South Australia and Victoria shows that under regular top-dressing with superphosphate the perennial grasses tend to be replaced by annual exotics, such as *Trifolium* spp., *Vulpia bromoides* and *Bromus* spp.; the increase in legume growth, either subterranean clover or naturalized exotics, paves the way for the laying down of permanent sown pastures by building up soil fertility.

The effect which increased areas of improved pastures may have on the production of super-fine wools is not yet quite clear. Marston (**7**) has shown that the diameter of the wool fibre of the Merino sheep may be greatly influenced by the level of the protein in the foodstuff. Clunies-Ross and others (**3**) carried out tests on *Danthonia* pastures at Yass, in New South Wales, using comparable sheep on natural pasture and on a pasture in which subterranean clover had been incorporated. Wool production on the improved pasture was 33.6 lb. per acre, compared with 8.92 lb. per acre on natural pasture. There was no difference in the colour or texture of the wool from the two pastures. The wool from the improved pastures was in general 70/74's type, while that from the unimproved type was 74/80's. These authors concluded that grazing sheep with super-fine wool on improved pastures did not make the wool stronger, but definitely increased the live-weight and wool production per sheep.

Shrub-steppe

The next type of pasture to consider is the extensive shrub-steppe which covers millions of acres in arid and semi-arid western New South Wales and central and south-western South Australia. The shrub-steppe lies mainly within the 10-inch annual isohyet, and mostly receives 7 to 8 inches per annum. Moreover, the rainfall is extremely unreliable, much falling in light ineffective showers, or in heavy downpours. The best development of the shrub-steppe is within the winter-rainfall zone. This type of country carries large-bodied, strong-woolled Merino sheep.

The perennial herbage belongs mainly to the family Chenopodiaceae. Species of *Atriplex* (saltbushes) and *Kochia* (bluebushes) form an open community, individual bushes being about 2 ft. in height and separated by patches of bare ground. After good rain the latter are covered with an amazingly rich and dense cover of ephemeral annuals which disappear rapidly with the onset of dry weather. The only permanent cover is provided by the saltbushes and bluebushes. Trees are relatively unimportant in true bush country, although they occur in pockets and transitional zones. Excepting in the *Acacia* scrub zones, which occur on sandhills throughout the bush country, trees are generally absent from country receiving less than 8 inches rain per annum. Many of the trees in the transitional zones and " pockets " are

edible, for example, *Myoporum platycarpum* (sandalwood), *Acacia* spp., *Cassia* spp., and *Heterodendron oleifolium* (bullock bush). The saltbushes and bluebushes, the most important of which are *Atriplex vesicarium* and *Kochia sedifolia*, are very drought-resistant and highly nutritious. The former is the more palatable, but it is shorter-lived than the latter, and usually dies out after about 10 years. Regeneration depends entirely upon seed. The salt content of the leaves is high, and the protein content as high as 20 per cent. Several species of *Atriplex*, *Kochia*, *Rhagodia* and *Bassia* occur in different parts of the bush country. Wood (**13**) has shown in South Australia that all these plants are similar to *Atriplex vesicarium* in possessing tomentose microphylls which are capable of absorbing moisture from an atmosphere saturated with 85 per cent water vapour. The atmosphere above the shrub-steppe is, in fact, nearly saturated for several hours each day, because of the great diurnal range in temperature. The high pentosan content of the saltbush leaves enables them to retain the absorbed water and to resist desiccation. During periods of prolonged drought the bushes shed their wilted leaves until defoliation is complete. Regeneration occurs after rains by the growth of new shoots at the base of the old stems. *Atriplex vesicarium* also possesses short-lived feeding roots which are shed during dry periods. According to Ratcliffe (**10**), sheep do not fatten well when grazing on a saltbush diet exclusively, but will grow wool and lamb successfully. When the ephemeral herbage is abundant, sheep do not graze on the bushes very much, but eat them readily in times of drought. The ephemeral herbage consists mainly of winter-growing, drought-escaping plants. The main families represented are the Chenopodiaceae, Zygophyllaceae, Compositae, Cruciferae, Leguminosae and Malvaceae.

Stipa nitida is a very important summer fodder grass. It is an annual or short-lived perennial which becomes established among the litter around the bases of the saltbushes. Pastoralists base the carrying capacity of the land on the abundance of the ephemeral herbage. Although saltbushes make it possible for the area to be stocked permanently, they are regarded mainly as fodder reserves. Thus, the rainfall being variable and unreliable, the carrying capacity also varies widely at different periods. On the average, the shrub-steppe is stocked at the rate of fifty to sixty sheep per square mile. Country growing saltbushes alone will carry about twenty-five sheep per square mile.

So far as the saltbushes are concerned, it has been proved that intermittent heavy stocking is the best practice. Bushes in ungrazed country are sparse and stemmy. Grazing maintains them in a healthy condition by removing the terminal buds and stimulating the lateral shoots. Intermittent grazing also allows seedlings to become established. The death and breaking-up of the saltbushes during dry spells has led to serious wind erosion in bush country.

Acacia semi-desert scrub

Interspersed throughout the shrub-steppe of New South Wales and South Australia are scattered areas of *Acacia*-semi-desert scrub. The vegetation consists of trees and shrubs, the most important of which is the edible mulga (*Acacia aneura*).

Associated with this species are the following shrubs :—*Acacia tetragonophylla* (dead finish), *Solanum* spp., *Eremophila* spp., *Cassia* spp., *Dodonaea* sp., etc. Mulga itself rarely exceeds 20 feet in height, and has a characteristic umbrella-like top. This type of scrub is found on rocky ranges, where it forms a climax association, and on sandhills and sandy country generally. The water relations of these soils are better than those of the saltbush steppe. Thus *Acacia* spp., which will not grow on the hard loam soils inhabited by bush, will flourish on sandhills scattered throughout the same area.

There are large areas of sandy country in South Australia and New South Wales covered by *Acacia* scrub, the natural regeneration of which is being prevented by sheep and rabbits which eat the slow-growing young seedlings. The same thing is happening to other edible shrubs and trees, such as species of *Myoporum* and *Cassia*. Apart from the trees and shrubs, there is almost a complete absence of perennial plants on the sandy soils. The ground flora of the sandy country consists mainly of ephemerals or short-lived plants, the most characteristic being *Stipa nitida, Tetragonia expansa, Blennodia canescens* (mustard bush), *Kochia* spp. (annual bluebushes), *Zygophyllum* spp., and various composites. The mulga scrub of the sandhills is, therefore, unsuited to permanent stocking. Once the flush of ephemeral plants has passed, the only reserve fodder is provided by the trimmings and droppings from edible trees and shrubs.

On the rocky hills, the ground flora is of a type more suitable for grazing purposes. The most important species are *Cheilanthes tenuifolia, Panicum* sp., *Stipa* spp., *Trisetum pumilum, Danthonia semiannularis, Rhagodia nutans, Erodium* spp., *Tetragonia* spp., *Chenopodium* spp., *Bromus arenarius, Pappophorum nigricans, Neurachne Mitchelliana, Calandrinia* sp. and various composites. The disappearance of the mulga and other edible shrubs is leading to serious soil drift on the sandhills and sandplains.

Mallee scrub

Mallee scrub occupies large areas in north-western Victoria, south-western New South Wales, southern South Australia and south-western Western Australia. The principal plants are dwarf eucalypts, which vary in height from 6 to 40 feet. The average annual rainfall of the Mallee varies with different localities and ranges between 8 and 20 inches, most of which falls in the winter months. According to Wood (**13**), the Mallee may be regarded as a vast ecotone between the sclerophyll forest and the arid shrub-steppe. Being a transitional zone, it exhibits features of both the sclerophyll forest and the saltbush country. The true mallee, however, carries very little ground cover, and is not much utilized for grazing purposes. With the opening of the Mallee country in four States for wheat-farming, sheep have followed. The most common species after rain are *Vulpia bromoides, Hordeum murinum*, and annual saltbushes and bluebushes. The carrying capacity varies within wide limits. Wimmera ryegrass (*Lolium* sp.) has been successfully sown in parts of the Mallee, while portions of the Murray River section have been irrigated and perennial exotic grasses and legumes sown.

Cleared forest pastures

The close forest which extends down the east coast of Australia from the New South Wales-Queensland border has been utilized chiefly for dairy pastures. It is also found in the south-western corner of Western Australia. In its natural state, temperate forest provides only very poor grazing. The ground flora consists of scattered tussocks of *Themeda australis* and the coarse *Imperata cylindrica* var. *Koenigii* (blady grass). *Sporobolus elongatus* (Parramatta grass) and *Eragrostis leptostachya* (paddock love grass) are also common, while sub-dominant species include *Poa caespitosa*, *Danthonia* sp., *Stipa* sp., and *Cynodon dactylon* (couch).

Large areas have been ringbarked and cleared for the establishment of dairy farms. On the New South Wales coastal regions, *Paspalum dilatatum* and *Trifolium repens* form the basis of the summer pastures. Perennial ryegrass, cocksfoot, and subterranean clover are utilized extensively in winter pastures, especially in the southern portion.

The dairy pastures of Eastern Australia lie within the high rainfall zone of uniform distribution, and carry one animal to less than 5 acres. In Western Australia the temperate forest has been cleared and the area sown to introduced grasses and clovers. The rainfall per annum is about 25 inches, and has its main incidence in the winter months. Sheep are pastured at the rate of one per 1.5 to 4 acres. The export lambs of Western Australia are fattened on these pastures.

By 1870 most of the important sheep country in Australia had been settled, and except for an increase in Western Australia, there has been little variation in sheep numbers since that date. There is no doubt that the density of many of our most useful perennial forage plants has decreased enormously since 1870. It is equally apparent that naturalized annual legumes and grasses have played a large part in maintaining the stock numbers in semi-arid regions. With the sowing of pastures in the better rainfall regions, large increases in the carrying capacity can be expected.

The problem of overgrazing and soil drift in the arid pastoral area is a serious one, and its solution will necessitate large-scale re-adjustment of stocking rates.

References

1. Cashmore, A. B. An investigation of the taxonomic and agricultural character of the *Danthonia* group. Coun. sci. industr. Res. Aust. Bull. 69. 1932. pp. 23.
2. Coleman, J. M. A survey of the lamb-raising industry in Australia. Aust. Meat Board. Bull. 1. 1938.
3. Clunies-Ross, I., and others. The grazing of sheep on improved pastures; its effect on superfine wool. Coun. sci. industr. Res. Aust. Pamph. 71. 1937.
4. Collins, Marjorie. Studies on the vegetation of arid and semi-arid New South Wales. Pt. 1. *Proc. Linn. Soc. N.S.W.* 48. 229-66. 1923.
5. Davies, J. G., Scott, A. E., and Fraser, K. M. Natural pastures; their response to superphosphate. Coun. sci. industr. Res. Aust. Bull. 83. 1934. pp. 76.
6. ———— and Sim, A. H. The influence of frequency of cutting on the productivity, botanical and chemical composition, and the nutritive value of natural pastures in South Australia. Coun. sci. industr. Res. Aust. Pamph. 18. 1931.
7. Marston, H. R. The nutritive value of pastures for wool production. Der Nährstoffwert unserer Weiden hinsichtlich der Wollproduktion. *Rep. Fourth Int. Grassl. Congr. Gt. Brit.* 1937. Plenary paper, 26-30. [German summary, 29-30. Discussion, 30.] 1937.

8. McTaggart, A. A survey of the pastures of Australia. Coun. sci. industr. Res. Aust. Bull. 99. 1936.
9. Osborn, T. G. B., Wood, J. G., and Paltridge, T. B. The autecology of *Stipa nitida*. *Proc. Linn. Soc. N.S.W.* 56. 299-324. 1931.
10. Ratcliffe, F. N. Soil drift in the arid pastoral regions of South Australia. Coun. sci. industr. Res. Aust. Pamph. 64. 1936.
11. Taylor, G. The distribution of pasture in Australia. *Geogr. Rev.* 27. 291-4. 1937.
12. ———— Australian meteorology. Oxford, 1920.
13. Wood, J. G. The vegetation of South Australia. Adelaide, 1937. pp. 164. maps.
14. New South Wales, Bank Circ. 9. No. 1. 1939. The depreciation of soil productivity.

6. WEEDS OF AUSTRALIAN PASTURE LANDS

R. W. Prunster

Before the settlement of Australia by white men, the country was stocked only with representatives of its peculiar fauna, and it is reasonably safe to suggest that the indigenous grasses and herbage plants were not subjected to the severe strains of burning and overstocking. There were then no weeds, because the balance of plants had not been upset. With the introduction of rabbits, sheep and cattle, the biotic factor was radically changed, and the indigenous plants were subjected to more intense and closer grazing. The rapid extension of the pastoral industries during the past few decades to areas of low rainfall with their recurring droughts has caused a striking change in the flora in many areas. In many instances, the very palatable grasses like *Themeda australis* which were characteristic of the country are now rare, and have given place to species of the *Stipa* type, while the herbage is reduced in amount and in vigour, or has changed, a less valuable plant having become the noteworthy feature of the pasture, for instance, *Bassia Birchii*, (galvanized burr) in place of the more palatable saltbushes. In the good rainfall country, the sowing of exotic pasture species is a sound practice economically, but it is quite a different story where the rainfall is low. There the partially eaten-out areas remain denuded of their former vegetative cover, or there is invasion by weeds which become pests. With strikingly few exceptions, the plants which are regarded as pests of pastures are introductions, deliberate or accidental. *Opuntia* sp., *Xanthium spinosum*, *X. pungens*, *Homeria* spp., *Hypericum perforatum*, *Senecio jacobeaa*, *Emex australis*, *Argemone Mexicana*, *Chondrilla juncea*, etc., are among the important exotic weed pests.

It is difficult to make accurate estimates of the losses which are attributable to weeds in pastures—in fact, some pastoralists may state that a given plant, regarded as very undesirable by other graziers, is to them a standby during droughts. Nevertheless, it is evident that a reduction in carrying capacity resulting from the displacement of good pasture types by noxious species or the losses of stock from poison plants will affect the quantity of wool, meat and dairy produce, and the quality of the produce may also be reduced. A period of nutritional deficiency will cause a " break " in wool fibre, the presence of burrs reduces the value of fleeces, and some plants, for example, *Inula graveolens*, taint milk and milk products.

As another publication will deal with weed problems, only the briefest references are made here to a few examples (see article by G. A. Currie in Herb. Publ. Ser. Bull. 27, Jan., 1940). Investigations concerned with the control of weeds have been undertaken in State Departments and institutions, and more recently the C.S.I.R. in its Divisions of Plant Industry and Economic Entomology has been engaged in studies planned to achieve control in those cases where the problem transcends State boundaries or may do so. Collaboration is effected by having problems considered by committees representative of the C.S.I.R. and State Departments.

Noogoora burr (*Xanthium pungens* Walk.) is a vigorous seasonal species in river valleys and in areas subject to occasional flooding in Queensland and north-eastern New South Wales. It was introduced about the time of the American Civil War, in cotton seed from U.S.A. which was planted at Noogoora Station, Queensland. Attempts are being made to find an insect to control it, but so far only one, *Euaresta aequalis* Loew., a seed-fly, has been released for test.

Bathurst burr (*X. spinosum*), which reached Australia from South America, occupies more southerly areas than does Noogoora burr. It is also more widespread and constitutes the more important problem.

St. John's wort (*Hypericum perforatum angustifolium*) covers about a quarter of a million acres of plain and hill country in north-east Victoria. It was introduced about 1880, and escaped from cultivation towards the end of the century. *Hypericum* causes a dermatitis of light-coloured skin areas of sheep and cattle. Entomological control is being studied; in the meantime, where it is economic or worthwhile, common salt is used, and experiments are in progress to determine the effects of competition by suitable pasture mixtures.

Cape tulip (*Homeria collina*) from South Africa is a problem in parts of South Australia and Western Australia, and the species also occurs in Victoria and New South Wales. It is poisonous to stock, but fortunately it is not generally found in dense infestations. Again, control by the agency of competition from suitable pasture mixtures is being investigated.

Stinkwort (*Inula graveolens*), supposed to have been introduced into South Australia from Germany about 1863, is more troublesome in the pastures of Victoria and New South Wales. It is abundant in pastures which have been overgrazed, because, being somewhat unpalatable to sheep and rabbits, it persists to the detriment of more palatable species.

Bracken (*Pteridium aquilinum*), blackberry (*Rubus fruticosus*) and sweet briar (*Rosa rubiginosa*) are serious only in neglected pastures. One of the most remarkable pests of pasture areas in Australia was the group of species of *Opuntia* known as prickly pears, which covered some sixty million acres in the 25 to 30 inch rainfall areas of Queensland and northern New South Wales by about 1925. The pest was increasing at the rate of approximately one million acres annually, almost entirely over valuable grazing country. It happened to be introduced without accompanying natural enemies, and therefore only climatic factors could limit its extension. Insect enemies were sought in South and North America, and a number were used. *Cactoblastis cactorum* from the Argentine has been mostly instrumental in the practical

control of the main pest, *Opuntia inermis*, and to-day stock are grazing over most of the area where a few years before none could be carried (see article by A. P. Dodd in Herb. Publ. Ser. Bull. 27. Jan., 1940).

Mexican poppy (*Argemone mexicana*), double-gee (*Emex australis*) and khaki weed (*Alternanthera achryantha*) are introduced weeds of pastures, the second being more important in Western Australia than in other States. Double-gee and khaki weed are eaten to some extent by sheep, but they are of lesser pasture value than other plants, and the strong, spiky processes on their seeds cause considerable injury to the feet of sheep and reduce the quality of the wool.

Obviously, this by no means exhausts the list of weeds occurring in pastures, but the plants cited serve to show that in most instances control measures must be bound up with proper pasture management.

7. SOME INSECT PESTS OF PASTURES IN AUSTRALIA

A. L. Tonnoir

The most spectacular pest of pastures is the Australian plague locust, *Chortoicetes terminifera* Wlk.; fortunately, outbreaks do not occur every year, but generally during or following the peaks of summer rainfall. The over-wintering eggs hatch during September; the hoppers remain in bands, and take six weeks to reach the flying adult stage, when they start to migrate on a large scale. There are usually two generations during the good season, sometimes three, and exceptionally a partial fourth. This locust's activity ceases during April, but sometimes extends to May when young wheat is attacked. Eggs are laid at a depth of 1 inch in the soil in selected areas known as "egg-beds", usually patches of dry hard soil. The eggs are enclosed in a sheath or pod, which contains from thirty to forty eggs. Losses of fodder due to locust depredation have been estimated at more than 1 million pounds in certain years in New South Wales alone. In that State, more than £40,000 was spent on control measures during the last outbreak. The small plague grasshopper, *Austroicetes cruciata* Sauss., is also responsible for damage to pastures, especially in New South Wales; in other States it confines its attacks mostly to wheat. Losses due to this species, however severe they may be because they occur in the spring, are of short duration, the species having only one generation a year; otherwise its life history is similar to that of *C. terminifera*.

The curl grubs (Scarabaeid beetle larvae) of various kinds, although less spectacular because they work underground, are actually taking a considerable toll of our pastures. Some are above-ground feeders, although living in burrows, for example, *Aphodius tasmaniae* Hope, which cuts grass blades at night and consumes them afterwards in the burrows. The grubs of many species of the genera *Scitala*, *Diphucephala* and others, which feed on the roots of grasses, are often present in very large numbers just under the sods. Nearly all these beetles have only one

generation a year in most parts of Australia ; a few, on the contrary, may spend several years in the ground in the larval stage. The beetles often emerge from the ground in large numbers at the same time, usually in December. They feed on trees or bushes, and drop their eggs indiscriminately on the soil shortly after emergence.

The underground caterpillars of various species of the genus *Oncopera* (Lepidoptera, Hepialid) are important pests of pasture, especially in parts of Australia where the rainfall is high (30 inches or over). Tasmania is, therefore, more seriously affected than the other States. There are three species there, one of them, *O. intricata*, the Tasmanian grass grub being peculiar to the island. The eggs are dropped indiscriminately on the ground after a short nuptial flight, which takes place *en masse* at dusk, during a very short period of the early summer (about Christmas), some years during a single night only. The eggs hatch within a few weeks, and the small caterpillars live on a frail webbing at the foot of tussocks ; they grow very slowly, and start burrowing in the late summer. Each caterpillar digs a single vertical pit, and builds on the surface of the soil a covered way formed of debris and webbing. It feeds on the surface during most of the winter, and is fully grown by October ; it then changes into a pre-pupal stage, during which it is still active but does not feed ; it is then completely white. The pupal stage lasts about three weeks. There are three species known from Victoria, where they cause serious damage (mostly in Gippsland). Several species are also found in New South Wales and in Queensland (Atherton Tableland), but there they are of lesser importance. The most widespread species in south-eastern Australia is *O. rufobrunnea*.

There are also several species of cutworms (Noctuidae), which at times occur in great numbers ; such are the army worms, *Spodoptera exempta* Wlk., *Cirphis unipuncta* Haw, *Spodoptera mauritia* Boisd., the brown cutworm, *Euxoa radians* Guen., and the grass moth, *Apina callisto* ; the cotton cutworm, *Prodenia litura*, has also been found attacking grass. The " grass caterpillar ", *Achrana licarsisalis* (Pyraustinae), the web-worm, *Sclerobia tritalis* (Phycitinae), the Crambid *Ptachostola microphaella* Wlk., and the Oecophorid *Philotola productella* Wlk. should also be added to this list of pasture pests.

8. GRASSLAND IMPROVEMENT AND RESEARCH IN NEW SOUTH WALES

J. N. Whittet

The State of New South Wales includes a wide range of climatic zones and soil types, and consequently the pasture problems requiring investigation are of a very varied and complex nature. Pasture research is in progress at eight Experiment Farms, the Hawkesbury Agricultural College and the Rice Research Station which is located near Yanco on the Murrumbidgee Irrigation Area. In addition, certain major investigations are being conducted by District Agrostologists on farmers' and graziers' properties in representative areas of the State ; these officers operate from the following headquarters :—

Lismore	—	North Coast
Maitland	—	Central Coast
Glen Innes	—	Northern Tableland
Scone	—	Upper Hunter and Liverpool Plains
Goulburn	—	Southern Tableland
Orange	—	Central Tableland, Central Western Slopes and Plains
Narrabri	—	North Western Slopes and Plains
Wagga Wagga	—	South Western Slopes and Riverina

The co-operation of the Chief Agrostologist and members of his staff with other branches of the Department of Agriculture in investigating animal nutrition problems, chemical composition of pasture species, suspected cyanogenetic plants, biological studies of pasture legumes, new species of pasture plants from overseas and improved types raised by the Plant Breeding Branch, forms a major part of the operations of these pastures specialists.

1. Coastal Districts

In coastal districts, *Paspalum dilatatum* and *Trifolium repens* are the dominant plants in sown pastures; heavy frosts affect the grass, and consequently species which will provide succulent feed during the winter period and withstand the aggressive summer growth of *P. dilatatum* are needed. Strain and introduction trials are in operation throughout the coastal zones to determine the most suitable species for these areas; *Phalaris tuberosa* is proving superior to all other perennial grasses on the Big Scrub soils of the Far North Coast, and, although inferior to certified *Lolium perenne* in its first year on other soil types, it invariably produces greater persistency in subsequent years.

The aim of every coastal dairy farmer should be the encouragement of a dense sward of *Trifolium repens* in his pastures; the best strains of this species are being tested in demonstration plots on farmers' properties. Adequate supplies of lime and phosphate are being used to maintain a vigorous growth of this species. In average years, good superphosphate responses are obtained on the North Coast on (1) alluvial and (2) black basalt-derived soils; on the brown, red-brown and red soils of the Volcanic Big Scrub areas, however, it is difficult to obtain a satisfactory superphosphate response owing to the capacity of these soils to hold the soluble phosphate in an unavailable form. Soil and pasture analyses are being continued on this problem, together with applications of fertilizers and lime compounds. A section of this investigation includes the determination of soil nitrogen levels following various treatments; the soil fertility level of Big Scrub soils has been reduced by constant stocking, and the influence of legumes (principally cowpeas and red clover), prior to sowing winter pasture mixtures, will be computed.

In coastal areas the podsols and basalts have been badly leached of their bases, with the result that low-fertility-demanding species (mainly unpalatable grasses) have replaced the superior species. Efforts by landholders to establish perennial high-fertility-demanding species on soils which lack organic matter and are badly leached have resulted in failure, and the value of (1) temporary legumes such as cowpeas and red clover, (2) the use of *Trifolium subterraneum* as a pioneer plant, and (3)

temporary pastures of Italian ryegrass and red clover in the rotation prior to planting permanent mixtures is being demonstrated.

With the object of ensuring feed in plenty and variety all the year round, and a ration which contains all the elements of nutrition, the methods of pasture improvement which are being demonstrated to coastal farmers are (1) the renovation of the *Paspalum* pasture by ploughing or working with some form of renovator, (2) sowing other grasses and clovers, particularly winter growers, (3) top-dressing, and (4) subdivision of paddocks to enable a system of rotational grazing to be adopted.

2. Tablelands Districts

The production of wool and fat lambs and the raising of beef cattle are the main sources of pastoral wealth on the Tablelands. The greatest need is for species which will provide succulent, green pasturage during late autumn, winter and early spring months ; at these periods, in the majority of cases, the natural pastures fail to produce satisfactory growth owing to the cold conditions which prevail. The native grass areas consist mainly of summer growing species which are plentiful and generally bulky at the beginning of the winter ; these all dry off very rapidly in late autumn and become somewhat hard and non-nutritious, and animals (particularly cattle) grazing on them during winter months soon lose condition and frequently die from impaction.

As soil moisture is one of the main limiting factors in the establishment and maintenance of perennial plants in a pasture, experiments are in operation at the New England Experiment Farm, Glen Innes, to test the efficacy of light versus heavy seedings of pasture mixtures.

In the cooler zones of the Northern Tableland, lucerne is a very useful crop, where it can be grown, not only for grazing, but also for occasional cuts of hay for feeding to stock during the cold winter period ; in the establishment of lucerne on deep soil areas, successes are now being recorded by inoculating the seed and including nitrogen at seeding in the fertilizer application. Sulphate of ammonia provides the plants with their early nitrogen requirement. These tests are being extended to soils previously considered unsuitable for lucerne culture.

The increasing interest in grassland work both in the higher rainfall districts and drier areas of the Central Tableland is due to the realization that pasture improvement increases carrying capacity, whereas continuous wheat growing decreases soil fertility and induces soil erosion.

In Southern Tableland zones the rainfall is mainly of winter incidence, evaporation is low and winter feed is deficient in natural pastures owing to the cold conditions which operate together with a lack of clovers and trefoils in most districts ; phosphate appears to be deficient in most soils and taking the localities as a whole there are relatively small areas with soil commonly accepted as " fertile ". Where the rainfall is fairly high, many soils of low fertility and low moisture-retention capacity appear to maintain a sward of mixed pasture quite satisfactorily, with no previous building up by subterranean clover ; in the lower rainfall sections the species resistant to dry weather, *Phalaris tuberosa* and lucerne, must receive major consideration when recommending seed mixtures for sown pastures.

The improvement to be effected on the Tablelands will depend largely on the climatic conditions and soil types existing in the various districts, but the main methods to be adopted can be classified under the following headings : (1) the planting of winter grasses and clovers ; (2) top-dressing with superphosphate ; (3) the establishment of areas of grazing lucerne, and (4) efficient care and management of grazing areas in order to preserve the best types of natural pasturage, and to prevent overstocking and invasion by rabbits.

3. The Slopes, Plains and Western Divisions

Wool is the main produce in all these zones ; fat lambs and beef stock are also produced in the more favourable rainfall areas. These Divisions vary greatly in climatic and soil conditions, and thus the methods of pasture improvement must be varied accordingly.

In the Central Western Slopes, South Western Slopes and Eastern Riverina, graziers and farmers sow extensive areas of subterranean clover, lucerne and Wimmera ryegrass, whereas the last two species are the main ones planted in the North Western Slopes ; the grazing mainstay of the latter area is the phenomenal growth that occurs in native grass paddocks during average summer seasons. Mitchell grass, *Astrebla* sp., Flinders grass, *Themeda* sp., Panic, Star, Plains Early Spring, Brown Top and some species of Love grasses are particularly drought-resistant and provide valuable pasturage for all classes of stock. Most of the pasture areas of the Coastal, Tablelands and Slopes Divisions give economic responses to the application of superphosphate. This is not the case with most of the grasslands of the North Western Slopes, where the majority of the soils appear to be well supplied with available phosphoric acid.

Low rates of seeding, 2 to 4 lb. per acre, have been responsible for the extension of the grazing lucerne belt to regions where the annual precipitation is as low as 15 inches. Seedings below 2 lb. per acre are at present under investigation and rates of 0.5 to 1 lb. are proving valuable in light rainfall zones.

The subterranean clover—superphosphate combination is the basis of pasture improvement in the South Western Slopes and Eastern Riverina ; mixed farming has in this clover and lucerne effective counters to soil erosion, decreasing soil fertility and weed growth.

In marketing fat sheep of any kind, especially lambs for the export trade, it is essential that the flesh be free of grass seeds. If good clean pastures, such as those obtained in Eastern Riverina and parts of the Western Slopes with Wimmera ryegrass, lucerne, subterranean clover, etc., are available in spear grass country, fat stock can be marketed free of this deleterious " seedy " material.

4. Natural Pastures in the Dry Areas

In the Plains, Western Riverina, and the Western Division, the care and management of pastures, and the conservation and planting of edible trees and shrubs are the main forms of improvement, as the native grasses, herbage, saltbushes, fodder shrubs and fodder trees are the chief source of supply of stock feed. Native drought-

resistant grasses should be encouraged to seed and spread by stocking lightly when the plants show signs of seeding. As soon as seed has ripened and fallen, normal stocking can again be adopted. A system should be practised whereby a number of paddocks are allowed to seed each year, and the grass swards thus enabled to thicken considerably ; continued neglect to conduct such operations will soon result in the total disappearance of these grasses and the appearance of worthless weed plants. Research into the management of native pasture areas in order to maintain the most desirable species in the sward, introduction and testing of drought-resistant species of forage plants from other countries and the problem of re-establishment of semi-arid and arid native pasture plants are projects of major importance which are receiving attention in these dry areas.

In the low rainfall zones of New South Wales, difficulty is experienced in obtaining a satisfactory establishment of hardy, native pasture species ; low viability of seed, small seed yields and dry climatic conditions all mitigate against rapid and effective seedling establishment of these drought-resistant species. Chemical research and storage tests are being conducted in an endeavour to improve in particular the germination of drought-resistant Gramineae.

5. Chemical Investigations

A feature of pasture investigations during the past three years has been the increased attention given to the chemical aspect of agrostological work. New projects commenced this year in which chemical analyses will play an important part are :

(1) Seasonal and annual variations in the yields and chemical composition of natural and sown pastures.
(2) The preparation of a pasture map of New South Wales which will record the dominant pasture species, and also indicate major soil types and their composition.
(3) An investigation into the management of Sudan grass in an endeavour to reduce the danger of prussic acid poisoning.

In addition to the above the following major chemical investigations are to be continued :

(4) The analyses of pasture swards variously treated with fertilizers.
(5) A survey of pasture soils in the higher rainfall zones to record further the pH and available P_2O_5 content of such areas.
(6) The analyses of dominant pasture species of the North Western Plains to register their forage value during each of the four seasons of the year ; this work will give an indication of the necessity for supplementary feeding at given periods.

In the first item, the trial will compare the seasonal and yearly fluctuations in natural and sown pastures ; botanical and chemical analyses will be recorded and quadrat yields obtained at monthly intervals or more frequently during favourable periods.

In the second—the pasture map—major soil types will be classified and the various classes (conforming as closely as possible to soil series) defined ; details on mode of formation, profile, physiography and vegetation will be collected.

Pasture vegetation will be recorded and classified into dominants and associate species of (a) grasses, (b) clovers, (c) other forage plants, and (d) weeds ; timber cover will also be listed.

In the case of item three, it has been demonstrated that the HCN content of Sudan grass depends greatly on (a) the stage of growth, and (b) ratio of readily available nitrogen to readily available phosphorus in the soil. By a combination of grazing management and the manuring of phosphate-deficient soils, it appears possible to reduce the amount of cyanide to a level which will make the grass safe for stock.

Irrigated pastures are receiving special attention by a pasture specialist who is devoting the whole of his time to specialized work in establishment, management and watering studies ; in addition, co-operation with plant breeders is being undertaken with the aim of producing improved pasture types for irrigation areas. The use of temporary pastures in the rice rotation and for fat lamb raising is of major importance in the agricultural and pastoral development of the Murrumbidgee Irrigation Area.

General

Specialized trials comprise strain tests of the major species of grasses and clovers, plant association trials and rates of seeding pasture mixtures.

Plant association and strain trials are proving valuable by drawing the attention of landholders to the necessity for adhering strictly to the Chief Agrostologist's mixture recommendations, and also to the use of approved strains of pasture species.

The world's most promising strains of the major species sown in high rainfall zones are under test ; a special feature has been the introduction from other countries of species resistant to dry weather, and these are being compared with the best of our native drought-resistant pasture plants. All new introductions are examined for detrimental features, particularly piercing or burr-type seeds, presence of alkaloids and HCN in Gramineae.

In all major research projects the plots are randomized and in most cases replicated six times.

The certification of pasture plant seed is carried out with the major species used in sown pastures in New South Wales.

9. PASTURE RESEARCH AND DEVELOPMENT IN VICTORIA

R. L. Twentyman

The State of Victoria, situated at the south-eastern extremity of the Australian continent, and lying chiefly between latitudes 36° and 38.5° S., comprises an area of 87,884 square miles. Except in the north-western portion of the State, climatic conditions are very favourable for the growth of pastures consisting of persistent perennial species.

The rainfall, which is generally the most important factor controlling the growth of the pastures, varies from 10 inches per annum in the north-west to over 60 inches in the eastern highlands. Except for the eastern end of the State, where fair summer rains are experienced, most of the rain falls during the winter and spring, and the summer months are usually too dry to favour pasture growth. Of the whole State, 66 per cent has a mean annual rainfall of between 15 and 40 inches, the cultivation of cereal crops being most important in the drier north, while the wetter southern areas are mainly devoted to pastures.

Of the total area of 56 million acres, approximately 33 million have been, or are in the process of being taken up as freehold land, and the remaining area of 23 million acres of crown land consists mainly of forest reserves, inferior grazing land, semi-desert and mountainous country. In March, 1937, there were in the State 17 million sheep, 2 million cattle, 350 thousand horses, 300 thousand pigs, as well as 6 million acres under cultivation.

Victorian soils

The soils, which vary from rich volcanic loams to almost sterile siliceous sands, usually possess marked characteristics according to the parent rock material from which they have been derived. The soils of the main pasture districts are as follows :

Gippsland. Fertile grey loams derived from Jurassic mudstones (Korumburra, Poowong). Deep red crumbly soils derived from the Older Basalt (Warragul). Recent alluvium and peat swamp soils (Trafalgar, Koowee-Rup).

Central District. Soils mainly yellow to brown clay-silts derived from Silurian or Ordovician shales and mudstones, with coarse gritty granitic soils, and limited areas of rich volcanic soils.

North East. Soils mainly brown clay loams and sandy loams situated on extensive alluvium deposits derived from the adjacent highlands.

Western District. Consists of an extensive basaltic plain, the soils of which are mostly shallow retentive buck-shot silts interspersed (in the south mainly) with limited areas of rich soils adjacent to volcanic cones. Between the basaltic plain and the coast are grey loams derived from Jurassic mudstones and poor sands and silts formed from Tertiary deposits.

The native flora

The Gippsland hill country originally carried a tall dense eucalypt forest, the common species being bluegum (*E. globulus*), white mountain ash (*E. regnans*), messmate and stringybark, with *Tetrarrhena juncea* and scanty *Danthonia* as the only grass species of any importance.

The central District and the North East pasture areas were originally closely timbered with grey and yellow box, peppermint and stringybark, with limited areas of rather sparse pastures consisting of *Danthonia* spp. Kangaroo grass, *Stipa* spp., *Microlaena*, *Agropyron*, and other species in smaller amount.

The basaltic area of the Western District was originally mainly savannah and treeless plains, the north-western portion of the area carrying an open forest of red gum (*E. rostrata*). The natural pastures of this area consisted mainly of *Danthonia*, Kangaroo grass, *Eragrostis*, *Microlaena*, *Agropyron*, *Poa caespitosa* with other species of lesser importance.

Agricultural settlement in Victoria was first confined to the more open areas ;

in the early years the natural pastures provided ample grazing for the limited flocks and herds, while later ring-barking and clearing of the timber increased the grazing capacity. With the advent of cultivation and cropping, new species of grasses and clovers were introduced, some accidentally as weeds, others intentionally as desirable pasture species. Some of these new species, finding conditions favourable for their development, multiplied and spread rapidly, and are now in many instances almost as widespread as the native grasses. Perennial ryegrass (*Lolium perenne*) Yorkshire fog (*Holcus lanatus*) and white (*Trifolium repens*), cluster (*T. glomeratum*), suckling (*T. dubium*), and knotted clovers (*T. striatum*) flourished on the better soils of the Western District, while on the cultivated areas of the drier north the introduced annual species, barley grass (*Hordeum murinum*), soft brome (*Bromus mollis*), hair grass (*Festuca bromoides*), hop, cluster and woolly clovers (*Trifolium procumbens, T. glomeratum, T. tomentosum*) and burr trefoils (*Medicago* spp.), etc., replaced the perennial native pastures destroyed by cultivation.

The settlement of the hill country of Gippsland was a later development, and the clearing of the dense forest and sowing of pasture species on the burn enabled prolific pasture of cocksfoot, ryegrass, red and white clovers to be established.

Factors limiting development of pastures

The initial disabilities due to lack of stock, inaccessibility and the necessity for clearing and introduction of pasture species having been overcome, it became evident that other factors limited the development of the pastures. In the North, rain was the most important factor controlling pasture growth ; owing to the light and irregular rainfall and the low carrying capacity of the pastures, crop cultivation has become more important in this area. In the South, except for very limited areas, the fertility of the usually podsolized soils was low, the winter rainfall excessive for crops, and pastures assumed greater importance.

With the introduction of superphosphate about 1892, it was found that the cereal crops could be greatly stimulated by its use. Soil analyses indicated that Victorian soils were generally low in phosphates, and field trials demonstrated very marked increases in growth from the use of the fertilizer superphosphate. Departmental trials conducted in 1901 and 1902 at a large number of centres in the wheat belt showed that, compared with an average of 10.4 bushels of wheat per acre for unmanured plots, those receiving 51 lb. superphosphate per acre gave a mean increased yield of 47 per cent. It was further observed that the volunteer pastures, which subsequently developed among the stubbles on the fertilized land, made much stronger growth than those on the stubbles of the unmanured crops.

Pasture top-dressing

The use of superphosphate became general for cereal cropping, but there was very little progress in extending its use to the stimulation of pasture growth. Isolated farmers at Port Fairy and Cowley's Creek used phosphatic manures for top-dressing pasture land with good results, but it was not until 1920 when the results of the Department of Agriculture trials, begun at the Experiment Farm at Rutherglen and

Wyuna in 1912, became known, that any further consideration was given to the possibility of stimulating pasture growth by artificial fertilizers.

As a result of these trials and others subsequently conducted at Hamilton, Kyup and Willaura in the Western District, it was shown that increases of 100 per cent and more could be obtained from pastures top-dressed with soluble phosphates, as compared with the untreated pastures. Following the announcement of these results, a number of demonstrational pasture top-dressing trials were established in country centres by the Chamber of Agriculture, and these confirmed the fact that good responses to top-dressing with superphosphate could be obtained throughout the southern parts of the State. The discovery of this method of pasture improvement came at a time when it was being realized that Victorian pastures had deteriorated since settlement began, and the method was welcomed as offering a means of restoring the productivity of the pastures.

Further Departmental pasture top-dressing trials established at Warncoort, Benalla and Korumburra showed that large responses to phosphatic fertilizers could be obtained, but other fertilizers gave only indifferent or negative results. Sheep grazing trials commenced at Bannockburn in 1922 showed that the actual carrying capacity of the top-dressed pasture was more than double that of the unmanured area. The pasture top-dressing and sheep grazing trials begun at the Rutherglen Experiment Farm in 1912 continued to show an increasing response to moderate dressings of superphosphate and demonstrated that under proper management the spectacular improvement effected in the pasture could be maintained, and that top-dressing in the North East of Victoria was economically sound. As a result of this demonstration the practice of top-dressing pasture with superphosphate became increasingly popular in the North East.

Introduction of subterranean clover

In all these trials it was recorded that the increased pasture growth resulted mainly from the stimulation of the trefoils and the winter-growing annual grasses, and that the perennial native grasses themselves showed little or no response. This indicated that for top-dressing to be effective the pasture must either contain responsive species or suitable responsive species would have to be introduced. Subterranean clover was used and found to be almost ideal for this purpose, being well suited for the Victorian climate and capable of establishing and thriving under a wide range of soil conditions.

Top-dressing and the introduction of subterranean clover were extensively advocated by the Department of Agriculture and, as a result of widespread publicity including demonstrations given at numerous country centres by the Better Farming Train, by 1927 the practice of top-dressing had become firmly established throughout the State.

Nitrogenous fertilizers

After the value of superphosphate was definitely established, strong claims were made for the nitrogenous manuring of grassland, and experiments were commenced in 1929 at Darnum, Werribee, Warragul and Colac to ascertain the response to dress-

ings of sulphate of ammonia applied at intervals throughout the year. It was found that growth could be stimulated in the late autumn and early spring, but the short period of increased growth was followed by a suppression of the clovers and a prolonged depression in the pasture yield.

Experimental technique

Prior to 1939, measurements of pasture growth were made either by weighing the produce from a number of small quadrats which were clipped with sheep shears, or by cutting larger areas by means of the reciprocating knife grass hay mower and weighing the produce so obtained. Although these methods had enabled satisfactory conclusions to be made in respect to the value of superphosphate, they had serious limitations and were not suitable for measuring progressive seasonal growth in a manner as required, for example, for the nitrogen-time of application trials. Consequently in 1929 a new technique was adopted, motor lawn mowers being used to keep the plot swards in a pasture condition and frequent weighed mowings being taken from each plot.

An expansion in this new work was effected in 1932 when the Victorian Pasture Improvement League undertook to contribute funds to enable the Department of Agriculture to extend its work and conduct a more comprehensive scheme of pasture experiments throughout southern Victoria. This experimental work was designed to determine if further increases in the growth of Victorian pastures could be achieved by means of special manurial treatment, rotational grazing and the sowing of improved strains of pasture species.

The trials have revealed a marked similarity in the seasonal variations in growth of Victorian non-irrigated pastures, and it has been found that the manurial responses which are most conspicuous on the lighter textured soils are usually most marked during the early spring period.

Further, it has been recorded that the manurial response of a particular soil is liable to vary according to the management to which the pasture is subjected.

Since the early days of settlement, "English" grasses and clovers have been widely sown, and these have persisted successfully in Gippsland, the Western District, the Central District and in the North-East. In order to investigate the existence and the characteristics of local ecotypes of these introduced species, a Pasture Plant Research Station was established in 1929 at Burnley, a suburb of Melbourne.

Pasture Plant Research Station, Burnley

At this station extensive trials with the local strains of grasses and clovers in comparison with introduced strains have revealed the existence of local strains of outstanding pasture value. An extension of these trials to country centres has confirmed the value of these strains under general Victorian conditions.

Seed Certification Schemes and Seed Testing

This work has provided the basis of the government Seed Certification Schemes which include perennial ryegrass, subterranean clover, "Irrigation" white clover and

Phalaris tuberosa. The certified strains of seed found a ready market and have created a growing demand for certified seed, the superior value of which is now generally recognized.

The inauguration of the Seed Certification Schemes and the enforcement of the amended Agricultural Seeds Acts necessitated the provision of adequate seed testing facilities. The seed testing laboratory, completely equipped with modern apparatus, serves as the official seed testing station where all purity and germination tests are carried out. Trade samples are analysed and tested for a nominal charge, while samples submitted by farmers are tested free.

Species for arid areas

The search for suitable pasture species for the drier farming areas is being pursued at the Mallee Research Station, Walpeup. Here, under a 13 inch rainfall, promising results are being obtained with *Ehrharta calycina*, lucerne, an early strain of Wimmera ryegrass and the Mulwala strain of subterranean clover. Until recently Wimmera ryegrass had been the outstanding sown species in this dry area, but lucerne, sown at a reduced seeding rate, is now giving promise as a drought-resistant species.

Pasture under irrigation

Foremost among the factors limiting crop and pasture growth in the State is the absence of rain during the late spring and summer period. This disability has long been recognized, and an effort has been made to overcome it by means of numerous water storages which have been constructed on streams and rivers throughout the State. At first lucerne and summer fodders were the main crops grown on the irrigated areas, but early success with mixed grass and clover pastures at the State Research Farm, Werribee, and the Wyuna Experiment Farm, indicated that they might afford a more efficient means of utilizing the irrigation water. Five hundred acres of the State Research Farm, Werribee, are served by water from the Werribee Irrigation Settlement Scheme, and advantage was taken of this fact to conduct trials with both lucerne and permanent pastures under irrigation. The development of mixed pastures as the most important crop in the irrigated agricultural areas of the State has been the direct outcome of these experiments.

Lucerne was the basic crop in the development of the Victorian irrigation areas, but it has now been largely superseded by irrigated pastures, of which there are now approximately one-third of a million acres in the State. The flexibility of the pastures and their adaptability to heavy as well as light soils and to conditions too wet for lucerne have been proved. The high productivity, the variety and continuity of feed of the mixed pastures and the fact that they will withstand abuses in grazing and recover from over-watering or flooding by rain after irrigation have been strong points in favour of the pastures as compared with lucerne.

Intensive studies in relation to irrigated pastures have been carried out at the State Research Farm, Werribee, and manurial and species trials have been undertaken on a series of plots in the irrigation areas in the northern districts of the State. Species trials throughout the irrigation areas have demonstrated the suitability of

most European grasses and clovers and the superiority of certified strains of perennial ryegrass, cocksfoot, *Phalaris tuberosa*, white and strawberry clovers as components of irrigated perennial pastures. Tests have been conducted to ascertain the optimum rate and frequency of watering and to determine the most effective fertilizer for irrigated pastures. Under the system of watering used, the limit of profitable application of superphosphate had not been reached even with annual dressings of 4 cwt. per acre, while other fertilizers have not proved effective.

Intensive studies of the botanical changes brought about in irrigated swards as a result of differential grazing, manurial and watering treatments, have been undertaken at Werribee. The influence of the individual factors causing these changes is now well understood, and this work has provided a most useful basis for farm advisory work—the composition of the sward usually indicating quite clearly the previous management of the pasture.

Use of supplementary fodder

Grazing trials on irrigated pastures at Werribee have shown that, as a result of supplementing the winter grazing with hay gathered from a portion of the area during the spring, ten ewes per acre can be maintained throughout the year.

As an outcome of the publicity given to pasture improvement work, the area of first-class pasture in Victoria has increased rapidly in recent years. Top-dressing with superphosphate has become a very common practice in all pastoral and dairying districts of the State, and on most dairy farms grass hay has completely replaced oaten hay as a supplementary fodder for winter feeding. The area top-dressed annually has now risen to three and a half million acres, and over most of the State the grazing capacity of land top-dressed only every second or third year has been at least doubled. As might be expected, some readjustment of the stocking of these improved pastures has been necessary, for animals bred and adapted to scanty pastures are not able to take full advantage of, or to resist the diseases attendant upon this higher plant of nutrition. In some cases fat lambs are now raised on land previously regarded as unsound for sheep, and on which lambs could not be reared, while in others dairying is now practised where previously only meagre sheep pasture existed. Sheep diseases have naturally been troublesome with the improved pastures, but starvation, the greatest scourge that ever swept the State, has now been overcome.

The State has just emerged (1938-39) from probably the most severe and prolonged drought ever experienced with almost negligible stock losses, a fact which can be attributed almost solely to the large area of pasture that had been improved, and to the nutritious nature of the short bite that it provided.

Large though the area improved may be, there still remains a greater area awaiting improvement. Many small farms have been entirely improved, but many of the larger properties still have large areas in native grass, while on others, owing to extreme conservatism, pasture improvement work is only just commencing.

10. GRASSLAND INVESTIGATIONS AT THE WAITE AGRICULTURAL RESEARCH INSTITUTE, UNIVERSITY OF ADELAIDE

H. C. Trumble

Investigations on grassland which commenced on a small scale in 1925 received a strong impetus three years later from the co-operation and financial assistance of the Empire Marketing Board and the Council for Scientific and Industrial Research. When the Board was disbanded, and its contribution ceased, the Carnegie Corporation of New York contributed for a period of two years, while the Australian Wool Board has also co-operated since 1937. The C.S.I.R. has been associated with the investigations from 1927 onwards.

The original co-operative arrangement was directed towards an investigation of the mineral content of pastures ; studies in this field subsequently led to a marked expansion of the work, which was also stimulated by a growing realization in practice of the need for research of a more or less basic character relating to the general problem of pasture improvement.

Scope of investigations

More than seventy separate field experiments and some forty major pot culture experiments have been carried out in connexion with investigations of the mineral content and water requirements of herbage plants, the testing of pasture species and strains, improvement by selection and breeding, the design of seeds mixtures, response to fertilizer treatment and management, the development of technique, sampling methods and experimental designs, associated growth, the regeneration of semi-arid and arid pastures. The gradual accumulation of data, together with advances in agro-climatology, have made possible an ecological classification of South Australia into edapho-climatic zones to which the distribution of herbage plants and practical advances in pasture establishment have been related.

Ecological zoning

A commencement was made by plotting livestock distribution in relation to climax vegetation, as a means of delineating existing grazing areas on an ecological basis. In the subsequent analysis of the environmental complex, particular attention was devoted to climatic factors, new measures of which were derived. Following the correlation of climatic types and soil zones with the recorded distribution of seeded pastures and cereal crops, a series of edapho-climatic zones was constructed. Present work involves an extension of activities to southern Australia generally with a view to preliminary zonal classification, to be followed by an analysis of the variability factor within each major zone. Special attention has been given to the question of evaporation from soil surfaces.

Plant introduction and the testing of herbage species

Approximately 700 species have been studied as single plants, and a major proportion of these have been introductions from overseas. Very few introductions

have proved more valuable than species or strains already established in Australia. Palestine strawberry clover (*Trifolium fragiferum* L.), introduced in 1929, has proved vigorous over a range of soil types, and is now on the commercial seeds market, while *Paspalum vaginatum* (Swartz), introduced from South Africa in 1935, is promising for relatively saline habitats. As new introductions arrive they are subjected to field tests, at first under favourable conditions, then, if sufficiently promising, under more exacting treatment.

Pasture plant breeding and selection

An improved strain of *Phalaris tuberosa* is to be released shortly. Selection followed by group pollination in the case of perennial ryegrass has produced forms which are at present being tested as swards with existing strains. The testing and classification of types in prairie grass, subterranean clover and strawberry clover is in progress, with a view to the isolation and multiplication of the most desirable forms, while a breeding programme is being carried out with a view to the development of rhizomatous strains in lucerne.

Pasture technique

Methods have been developed to measure yield, seasonal productivity and botanical composition under grazing. A high degree of control has been attained in pot cultures and this aspect of the work has led to results that could not have been obtained with accuracy in the field. Work is in progress to determine the accuracy of various sampling methods, by the statistical analysis of data accumulated during the course of field experimentation, together with the results of uniformity trials.

Natural regeneration and succession in pastures

Succession has been followed in a natural pasture subjected to varying fertilizer treatment over fourteen seasons, and in a seeded pasture subjected to differential management over nine seasons. Natural regeneration is being investigated under arid conditions at Yudnapinna Station. Charting methods are being employed to record regeneration under varying natural and artificially imposed conditions.

Pasture establishment

Investigations have been made on a red-brown earth soil, podsolized sands and heath soils, an irrigated reclaimed swamp, heavy black soil, a granitic soil and on a mallee soil. The results have indicated suitable mixtures and methods of establishment for each soil and climatic type. At present, investigations are confined to arid and semi-arid pastures, in mallee and in shrub-steppe country.

Associated growth

A considerable body of evidence has been obtained from sand cultures to show that nitrogen is not normally transferred from legumes to non-legumes in South Australia prior to the senescent phase of the former. Slight excretion appears to occur under certain conditions, which recent work has been designed to determine.

Rhizobial factors

The Waite Institute has co-operated with the Soils Division of the C.S.I.R. in the investigation of strain variation and host plant relationship in *Rhizobium*, with a view to the development of efficient practical methods of legume seed inoculation.

Investigations of seed viability

These have accompanied the general programme throughout, and special methods of attaining satisfactory germination have been evolved for certain species. The conditions necessary for the germination of the more important herbage plants have been determined. Investigations are in progress relating to pasture regeneration in low rainfall areas.

Water utilization by herbage plants

The water requirements of the more important native and introduced herbage species have been determined in pot cultures, and the factors controlling the use of water by herbage plants have been studied. Investigations are in progress concerning the utilization of water by dryland pasture plants, as affected by soil type, periodic drought and management.

Fertilization of natural and seeded pastures

Permanent fertilizer tests are in progress on both natural and seeded pastures, to determine the nature of the response to phosphatic and nitrogenous fertilizers over an extended series of seasons. Close relationships have been established between pasture development and the available phosphate supply; the application of nitrogenous fertilizers has proved unsatisfactory. Investigations commenced more recently have been confined to the type of fertilizer treatment required by ironstone soils of a lateritic character and to co-operative work, with the Animal Nutrition Division of the C.S.I.R., on a calcareous coastal soil.

Pasture management

Comprehensive work in regard to pasture management has been commenced only fairly recently and has been made possible by the co-operation of the Australian Wool Board. This work now forms an important phase of the general agrostological programme. The effects of eighteen types of management are being investigated, in relation to the yield, botanical composition and general productivity of the pasture.

The effect of pastures on the grazing animal

The monthly live-weight increase and yearly wool production of Merino sheep have been used to compare the productivity of (a) unfertilized and top-dressed natural pastures, (b) top-dressed natural pasture and two types of seeded pasture. A third series is projected, in which an investigation will be made of the effect of pasture management on the grazing animal.

Chemical composition of herbage plants

The mineral content of herbage plants, as affected by species, stage of growth, soil type, fertilizer treatment, moisture supply and management, has been investigated in some detail. It is proposed to examine the chemical composition of species characteristic of arid conditions, grown on typical pastoral soils with varying soil moisture supply.

Physiological investigations

Detailed physiological studies have been carried out in pot cultures. These have concerned nitrogen metabolism on the one hand, with particular reference to the relation between the protein and amino-acid content of the leaves, and the general physiological basis of growth and development in pasture grasses on the other.

11. GRASSLAND RESEARCH OF THE SOUTH AUSTRALIAN DEPARTMENT OF AGRICULTURE

The South Australian Department of Agriculture is engaged in grassland research at its Kybybolite Experiment Station, and with reputable farmers and graziers throughout the agricultural districts of the State.

At Kybybolite, grassland work was first commenced in 1919 by Professor A. J. Perkins, and has since been extended from time to time. The initial work consisted of the treating of natural pastures by top-dressing with low-grade phosphate rock powders, and lime. Subsequently, treatments with soluble phosphate in various quantities, crushed limestone, and gypsum were added. The work was done on plots of 3.5 to 5 acres in area, and complete grazing results have been obtained from 1921 up to the present date, and are being continued. Professor A. J. Perkins reported the results of the work up to 1928 in Bulletin No. 224 issued by the Department of Agriculture, and showed :

1. increased carrying capacities ;
2. distinct alteration in the botanical composition of the herbage due to fertilizing ;
3. under chemical analyses the herbage from manured plots was richer in ash constituents ;
4. the bulk of residue of phosphatic fertilizer after nine years remained in the surface 2 to 3 inches of soil.

In 1924 work on the fertilizing of subterranean clover and Wimmera ryegrass pasture was commenced, using various quantities of water-soluble and acid-soluble phosphates, as well as lime and potash. This work is being continued, water-soluble fertilizers being applied annually, acid-soluble phosphates every five years, and lime every ten years. A report of this work up to 1928 was included in Bulletin No. 224, and in the Annual Reports on Pasture Work, compiled by L. J. Cook, and published in the Journal of Agriculture. The latest detailed Annual Report appeared

in Vol. 39, pp. 764 and 878; summarized results were published in an article entitled " Development of Red Gum Lands " in Vol. 40, p. 635. A further report on results up to 1938 is being prepared.

The development and production of Merino Comeback sheep were studied on both the natural and sown pasture from 1930 to 1936.

In 1935 a test of the sown pasture mixture of *Phalaris tuberosa* and subterranean clover was commenced in collaboration with the Waite Research Institute, and results of three years' work in comparison with the Wimmera ryegrass and subterranean clover mixture, and top-dressed natural pasture are being collated. The work will be continued for at least another two seasons.

In 1935 further sets of manure plots on Wimmera ryegrass and subterranean clover pastures were commenced to show, (1) the need of continued applications of water-soluble phosphate fertilizer, and (2) that the residual effect of 10 years' top-dressing with superphosphate at the rate of 91 lb. per acre per annum was not sufficient to maintain heavy producing pasture.

From 1930 to 1934 the use of nitrogen fertilizer in the form of sulphate of ammonia was tested, applied to (1) established Wimmera ryegrass and subterranean clover, and (2) sown mixed pasture of perennial ryegrass, *Phalaris tuberosa*, white and subterranean clovers. In dairy production, increases were obtained, but were insufficient to show that 1 cwt. per acre applications would be profitable.

In 1932 at Kybybolite the trial of pasture strains, the selection of plants with desirable characteristics and their multiplication was commenced, and is being continued. Strains showing persistent outstanding characters are being tried in other centres. Some success has been achieved with a robust, broad-leaved, high-tillering strain of Wimmera ryegrass, and this is being given an exhaustive trial in several districts. The work is being confined to the annual and perennial ryegrass, and to *Phalaris tuberosa* and *Bromus hordeacea* at present.

The introduction of fresh pasture species from interstate, and within this State, is studied by the establishment of small observational plots. The main collections are at Kybybolite and near Adelaide, and promising species are being tried at outside centres.

Preliminary tests of the use of lime and gypsum in conjunction with phosphatic fertilizer have been in progress at Kybybolite since 1919, and at several other special centres since 1936 and 1938. More comprehensive and detailed tests in conjunction with pastures and animal nutrition are needed with these soil amendments.

Our work with reputable farmers distributed throughout the agricultural areas of the State has been confined to demonstrational plots and not to close research, and consists of initial developmental tests in many districts, as well as the establishment of better pasture mixtures on the richer and better developed soils.

Since 1934 financial assistance granted by the South Australian Pasture Improvement Committee of the Australian Dairy Council has enabled much of this demonstrational work to be carried out, particularly in districts where dairying is practised and being developed, such as Adelaide Hills, Southern, South-eastern and Murray Swamps district.

Work on the richer and flatter lands of our South-eastern districts has commenced only recently, and demonstrational trial plots have been set out at Kingston, Robe, Hatherleigh and Tantanoola, while the work of Mr. N. J. McBain of Coonawarra with the pasture mixture of *Phalaris tuberosa* and strawberry clover gives an indication of a profitable mixture for these types of soil.

Plots established on the poorer soils of certain districts with very fair to good rainfall are tending to show the limit of successful growth of subterranean clover strains, naturalized *Trifolium*, and the various species of *Medicago*.

The improvement of the growth of the "medics", especially lucerne, in our wheat areas for the betterment of these soils is of importance, and demonstrational plots showing the establishment of lucerne are being set out, especially on the light mallee soils, at reasonable distances apart. A study of the thickness of stands and the amount of growth will be made, as well as attempts to record carrying capacity. The culture of winter cereals and annual grasses for grazing among the lucerne stands will also be investigated.

The use of lucerne, grasses with strong rootstocks, and other plants is also being demonstrated on soils affected by wind erosion.

Finally, for the betterment of grassland, a seed certification scheme has been adopted since 1936 on similar lines to that of other States of the Commonwealth; seeds of the following pasture species are being certified:—*Trifolium subterraneum*, lucerne, *T. fragiferum*, *Lolium subulatum* (Wimmera ryegrass), *Phalaris tuberosa*, *Lolium perenne* and *Oenothera latifolia*.

12. PASTURE INVESTIGATIONS OF THE QUEENSLAND DEPARTMENT OF AGRICULTURE AND STOCK

For the purpose of grassland research in Queensland, a division of the State into three main regions has been adopted. These are (a) the coastal plain, the eastern slopes of the coastal ranges and the Atherton Tableland; (b) the inter-mountain region, lying between the coastal ranges and the Great Dividing Range, and (c) the western slopes and plains.

The southern portion of the coastal region and the Atherton Tableland are important dairying areas. *Paspalum dilatatum* is the chief dairying grass, with Rhodes grass (*Chloris gayana*) and Kikuyu grass (*Pennisetum clandestinum*) used to some extent. Except for several dairying areas the remainder of the coastal region is devoted to the raising and fattening of beef-cattle on native and artificial pastures, and to agricultural crops.

Dairying and general agriculture are practised on a large area in the southern portion of the inter-mountain region, the main dairying grass being Rhodes grass. The remainder of the grazing area carries native pastures and is devoted to beef cattle.

The south-eastern portion of the western slopes and plains region, comprising the Darling Downs and Maranoa districts, is a rich agricultural, dairying and stock-raising area. On the Darling Downs the native pastures are largely supplemented by fodder crops for sheep and cattle. In the Maranoa, pastures of Rhodes grass

sown in the ashes of newly-burnt " scrubs " are used to a large extent for dairying and for supplementing native pastures for various classes of stock. The remainder of the huge area of western country carries native pastures of a semi-arid to arid type, which support a large population of sheep and cattle.

General investigations

For many years the main pasture interest of the Department of Agriculture and Stock was the encouragement of introduced grasses, particularly *Paspalum* and Rhodes grass, which early in the present century had proved to be outstanding in most of the dairying districts. Artificial pastures of these grasses now occupy about one million acres. Concurrent with this extension work has been the continuous testing of numerous introduced pasture plants, in which co-operation with the Commonwealth Council for Scientific and Industrial Research has been maintained for several years.

Advances in pasture improvement in other States and in New Zealand during the past decade stimulated the interest of Queensland dairy farmers and graziers in two special aspects of pasture improvement, namely, the use of permanent and self-regenerating winter-growing pastures, and the top-dressing of native pastures. With the assistance of dairying and fertilizer distributing interests, the Department was able to carry out many trials with temperate-climate plants which normally grow when *Paspalum*, Rhodes grass and similar species are dormant. In relatively few instances have valuable results been secured with such pastures, and practically nowhere is it possible to dispense safely with conserved fodder or annual fodder crops (such as wheat and oats), which normally are relied upon to supplement the summer-growing pastures during their winter-spring period of dormancy. It has not yet been found possible to conduct native pasture top-dressing experiments.

Improvement of pasture plants by breeding and selection has been attempted by the Department with only one or two species. Under a co-operative arrangement the Commonwealth Council for Scientific and Industrial Research is working in Queensland with some of the main pasture species. The Department has not yet adopted a certification scheme for any pasture seeds.

The reclamation of tidal mud flats is a matter to which some attention has been given. *Spartina townsendii* has been established in several localities, but has not yet demonstrated that it will prove satisfactory under subtropical and tropical conditions in Queensland.

Special investigations in the Coastal Region

The *Paspalum* pastures sown on rich rain-forest soils in the coastal area give satisfactory returns for many years, but ultimately deterioration becomes obvious. The renovation of this type of pasture has been the subject of investigation by the Department since 1924. It was soon demonstrated that mouldboard ploughing was an effective renovation practice, but no clear-cut results from fertilizer application and legume incorporation were secured in the early years of investigation. From 1931 to 1936 the Department, working in conjunction with the Queensland Pasture Improvement Committee, made many trials throughout the main *Paspalum* pasture

areas. It has been shown that mouldboard ploughing is the most effective mechanical method of renovation, while the cultivator type of *Paspalum* renovator is of use under some conditions. The value of applications of phosphatic and nitrogenous fertilizers subsequent to renovation and of surface introduction of white and red clovers was demonstrated on some alluvial soils but for the major soil types more investigation is required before definite recommendations regarding renovation can be made. Work of this nature is now in progress.

In some parts of the southern coastal region, old-established *Paspalum* pastures deteriorated to such an extent that complete replacement by the much less valuable blue couch grass (*Digitaria didactyla*) occurred. Measures for the restoration of this land to *Paspalum* pasture, or, alternatively, for the improvement of the existing pasturage are now being investigated.

On parts of the Atherton Tableland, deterioration of *Paspalum* pasture is accompanied by infestation by the white grub, and the determination of effective renovation measures is considerably more difficult than in other areas. The Department has been working for some years with the White Grub Investigation Committee, and considerable progress has been made towards the solution of the problem.

The development within recent years of the chilled beef export trade, together with the need to develop primary production other than sugar-cane growing in the rich areas on the far north coast, have led to investigations into the possibilities of cattle-fattening on tropical coastal pastures. At the present time, Para grass (*Brachiaria mutica*), molasses grass (*Melinis minutiflora*) and Guinea grass (*Panicum maximum*) are the major sown pastures in the far north. For the past year or more, investigations on methods of management, on feeding value and pasture mixtures have been in progress and a good deal of intensive investigational work is planned for the next few years.

Special investigations in the Inter-mountain Region

Problems relating to Rhodes grass pastures in the inter-mountain areas have received attention within recent years, particularly at the Callide Cotton Research Station. It has been demonstrated that the renovation of Rhodes grass pastures is readily effected on cultivable land by rotating the pasture with cotton or with a leguminous crop. Long-term experiments to supply information on many aspects of Rhodes grass cultivation are now under way. Methods of renovation which can be applied on steep slopes and rough country have yet to be determined.

Investigations are being made into moisture trapping on pasture slopes.

Special investigations on Western Slopes and Plains

To date, few investigations, apart from testing of species, have been carried out on the Darling Downs or in the Maranoa district, but a programme involving the study of Rhodes grass renovation, pasture-crop rotations and moisture trapping is to be initiated shortly.

Since 1936, problems associated with pasture deterioration on the semi-arid western plains have been the subject of continuous investigations. Grazing trials and life-history studies of the main pasture species are in progress.

13. GRASSLAND INVESTIGATIONS OF THE DEPARTMENT OF AGRICULTURE, TASMANIA

Following the demonstration of the productive capacity of top-dressed subterranean clover pastures little more than a decade ago, there has been a comparatively widespread expansion of artificial pastures both in the farming and grazing areas. Prior to this period, the results obtained from artificial pastures were seldom encouraging enough to warrant their extended use, and furthermore crop production was generally more profitable. Pasture areas cover a wide range of soils under varying climatic conditions. Their production is limited principally by extremes of temperature. Generally, the most productive period is from September to December, followed by the April to June period, while at other times production is much lower except in favoured situations.

The native pastures are mostly lightly timbered, the altitude varies from sea level to 4,000 ft. and rainfall from 18 to 40 inches. Where ploughable, this country is capable of carrying artificial pastures of perennial ryegrass, subterranean clover, cocksfoot and white clover, but the first two species are the most popular. On this country most of the earlier research, which had a direct demonstrational bias, was concerned with determining the species which could be successfully grown, methods of establishment, manuring, and management. Attention was also directed to the possibility of introducing clover following surface cultivation of the natural pastures.

As a result of investigations, pasture seedings have been practically standardized in these areas to 5 to 10 lb. perennial ryegrass, 4 lb. subterranean clover, and 1 lb. white clover. This is usually established on fallow land with a cover crop. Surface introduction of subterranean clover has proved satisfactory following light cultivation and accompanied by annual top-dressing with half a bag of superphosphate per acre. Pasture development is, however, slower under these conditions than following ploughing.

Manurial trials have indicated that superphosphate is the only manure giving economic results. The general dressing is 90 lb. per acre, but one series of trials on established subterranean clover pastures with 20 inch rainfall has indicated that 2 cwt. will give economic results over the first two years. These trials are being continued, and it is proposed to associate potash with the phosphate treatments.

Many of the earlier pastures established on the ploughed areas were of pure subterranean clover, and investigations have revealed that ryegrass can be introduced with beneficial results following surface working. Other problems receiving attention are those concerned with testing various species which might be expected to increase production or to extend the present period of production.

In the agricultural districts soils vary extensively, but the main types are of basaltic, diabasic, sandstone or mudstone origin. Rainfall varies from 22 to 50 inches with a fairly even distribution, and altitude ranges from 0 to 1,500 feet. In the past similar problems have been investigated on these areas as on the natural pasture areas, but more attention has been paid to investigation of suitable species. Naturally, a wider range of species is here in use, and greater quantities of cocksfoot, white clover, red clover, and alsike are employed.

Intensive stocking is adopted on much of this country, and consequently total production and the period of production are of considerable importance. Both are being investigated from the aspects of association of species, manuring, species strain, and grazing management. Within the last two years a number of trials have been established in which ryegrass, cocksfoot and *Phalaris tuberosa* are being tried in association with each of the following clovers :—wild white, Montgomery red, and subterranean. The grazing management of such trials is designed to give each grass the treatment resulting in maximum production. Minor trials with timothy and prairie grass are also being conducted in the same manner.

The introduction of certified pasture seeds necessitated their being tested against commercial samples ; results in general have been in favour of the certified strains, which are now being used extensively for pasture establishment. In conjunction with these, trials on a single plant basis were inaugurated to test pedigree lines and strains from different locations. At the same time, selection of Tasmanian ryegrass and cocksfoot was undertaken in an attempt to provide strains of New Zealand Pedigree Ryegrass, New Zealand Pedigree White Clover and Tasmanian Selected Cocksfoot most suited to local conditions.

A start has been made to determine the effect on later production of the time of initial grazing of newly established ryegrass—subterranean clover pastures. With the same type of pasture a trial is in progress to determine the effect of varying periods of resting between grazings. In the near future it is hoped to extend this type of trial to cocksfoot—white clover, and *Phalaris*—subterranean clover pastures.

Some difficulty has been experienced in obtaining normal growth from subterranean clover on a number of soils throughout Tasmania. Inoculation of the seed and of the soil proved unsuccessful and more recently investigations have been concerned with the response of these soils to various manurial treatments under laboratory conditions.

On the North-East and East Coast exists a belt of sandy land overlying a humus hard-pan. It is very light grazing land, but has a good rainfall. Trials have been inaugurated to determine what pasture species can be successfully grown, the best soil preparation for establishment, and the effect of manurial dressings of both major and minor elements. Results to date are encouraging enough to warrant further work.

With a wide range of soils and climatic conditions it is possible to touch only those problems which are of major economic importance to the State. In many cases, with the available staff, it is possible only to pursue investigations until broad recommendations can be formulated. This state of affairs must exist while pastoral development continues at its present rate, but later it may be possible to investigate some of the problems in more detail.

14. PASTURE INVESTIGATIONS IN THE NORTHERN TERRITORY

H. K. C. Mair

The grazing lands in the Northern Territory may be considered as comprising four regions :

(1) Central Australia, the northern extension of the southern Australia shrub-steppe community, which is perennially semi-arid, with an average rainfall of from 6 to 12 inches ;

(2) Victoria River District, adjoining the north-eastern borders of Western Australia ;

(3) Barkly Tableland District, being an extension of similar country from Western Queensland into the Territory ;

(4) the northern, coastal portion (Arnheim's Land) extending roughly to the fifteenth parallel of south latitude.

These three regions lie within the monsoonal area and are subject to arid conditions for half or more of each twelve-month period, with rainfall ranging from 12 inches in the south-east to 70 inches and over in the farthest north-west.

The Central Australian region carries on the average three beasts per square mile, and a number of settlers are also carrying sheep, now totalling around 15,000. The holdings are typically small, ranging from 300 to 1,000 square miles.

The Victoria River District carries on the average fourteen beasts per square mile, and consists of large stretches of Mitchell Grass downs separated by hilly country. Here the holdings are large, varying from 2,000 to 10,000 square miles. Victoria River Downs Station, with an area of 10,432 square miles, is reputed to be the largest cattle station in the world. No sheep are carried in this area.

The Barkly Tableland region carries on the average ten beasts per square mile and consists essentially of rolling Mitchell Grass downs. Holdings vary from 1,000 to 6,000 square miles. A small flock of 600 sheep is kept at Anthony Lagoon Station, but no advance has so far been made in increasing it.

The Arnheim's Land region consists mainly of savannah woodland of eucalypts, with deciduous species as co-dominants, and a wet-season (summer) herbaceous stratum of tall, coarse-growing members of the Andropogoneae. The greater part of this area consists of rock outcrop, to a great extent massive laterite. A large area in the north-east is Aboriginal Reserve. The holdings are small, and the carrying capacity extremely low. In the swampy areas adjacent to the Adelaide and Alligator Rivers, wild water-buffaloes are plentiful.

The whole of the monsoonal region of Australia differs from its homoclimes in that it has an essentially flat topography, the highest land being only 1,000 feet above sea-level. This feature allows no definite annual pasture route to be developed by owners, and hence stock wander over the holdings at random.

Pasture research has so far been confined to plant introduction, practically entirely at the Botanic Gardens, Darwin. Now that the pioneering stages are being passed by the cattle industry, past difficulties confronting the authorities in establishing research stations over the widely-separated type areas are now being overcome, and the facilities of air-travel will simplify operations over wide areas.

It is reported that Birdwood grass (*Cenchrus biflorus*) and Buffel grass (*Pennisetum cenchroides*) have been established for some years on trial plots in the Alice Springs district of the Central Australian region. Para grass (*Brachiaria mutica*) has been established for many years at Darwin on land liable to flooding in the wet season. *Stylosanthes sundaica* (Townsville lucerne), apparently accidentally introduced from the east coast, has become established within the last ten years on broken ground all over Darwin, and along the railway line over 100 miles inland. This is an annual legume which provides an abundance of pods from the middle of the dry season.

Although agricultural work has been almost entirely confined to crop species, numerous grass and legume species have been tried at the Botanic Gardens, Darwin, within the last three years, with a view to establishment and the obtaining of a supply of seed for trial on inland areas. Of these the most outstanding were *Cenchrus biflorus*, *Pennisetum cenchroides*, *Panicum antidotale*, *Melinis minutiflora* (molasses grass), *Brachiaria brizantha*, *Ischaemum laxum* and perennial Sudan grass among the grasses, and *Stylosanthes guyannensis* (a perennial legume), *Cajanus cajan* (pigeon pea—perennial shrubby type) and *Mucuna* spp. (*Stizolobium* spp.), particularly Mauritius and velvet beans, among the legumes.

The species of *Panicum*, *Brachiaria* and *Ischaemum* did not set any viable seed over two seasons, but vegetative propagation was easy. The remaining species gave heavy yields of seed with a high viability. The most outstanding species, it is considered, was the pigeon pea, original seed of which was received from the Council for Scientific and Industrial Research.

Work in the immediate future should be confined to trials of these and other suitable species on areas typical of the several grazing regions of the Northern Territory.

Among species tried without success at Darwin are—*Agropyron intermedium*, *A. cristatum*, *Apluda varia*, *Brachypodium phoenicoides*, *Chloris gayana* (Rhodes grass), *Digitaria pentzii*, *D. milanjiana*, *Ehrharta erecta*, *Ischaemum sulcatum*, *Panicum maximum*, *Pennisetum clandestinum* (Kikuyu grass), *Phalaris stenoptera*, among the grasses, and species of *Alysicarpus* and *Lespedeza* among the legumes.

15. GRASSLAND INVESTIGATIONS OF THE AUSTRALIAN ESTATES CO. LTD.

The Australian Estates Company Limited (incorporated in Great Britain), as the owner of extensive pastoral properties distributed throughout the more arid areas of New South Wales and Queensland, prosecutes a vigorous policy of investigation into the problems confronting it in these areas, in respect of both pastures and stock. The work is being done either by its own officers, or by these officers in co-operation with the Council for Scientific and Industrial Research, an arrangement which extends the sphere of service of the Council and increases the amount of scientific investigation done in the more arid areas of the Commonwealth.

At " Jemalong", Forbes, New South Wales, with an average annual rainfall

of 19.6 inches uniformly distributed throughout the year, trials with pasture species which have proved successful in the more favoured areas of southern Australia have, with the exception of Wimmera ryegrass and lucerne, given negative results. The success of dry country lucerne as a pasture has led to the establishment of manurial trials on this species, with the object of increasing production and longevity, but no responses were apparent last year (1938), which was extremely dry.

A manurial trial was laid down also on " natural " pasture, which consists of barley grass (*Hordeum murinum*), crowfoot (*Erodium* spp.), and trefoil (*Medicago* spp.), and is typical of extensive areas in that district. Although no response was seen in the dry year of establishment (1938), it is proposed to continue the trials.

Irrigated lucerne, watered by a pumping plant from the Lachlan River, has been grown at " Jemalong " without regular manurial treatment (the usual practice of the district) in the past ; trials were established last year with treatments ranging from 1 cwt. to 4 cwt. per acre, to determine the response and the most economic rate of application. No marked differences have been apparent during the first six months of the trial.

Successes with Wimmera ryegrass and lucerne as pasture plants at " Jemalong " have led to the establishment of trial areas on properties at Carrathool, Dandaloo, Warren and Nyngan, with varying results which have been largely attributable to the differences in the amount and incidence of the rainfall. In the preparation of land for dry lucerne, oats have been grown as a previous crop with sufficient success to indicate that agriculture has a part to play, no less than pasture improvement, in certain areas of Central New South Wales. With this principle in view the Company is making trial sowings of field peas, rape and other fodder crops, to determine the initial results which may be obtained with these species.

As lucerne, as a pasture, becomes heavily invaded with winter annuals such as barley grass and crowfoot, it is proposed to institute various cultivation trials this season (1939) for their control, and to determine the influence of this on the growth and length of life of the lucerne.

Investigations completed so far in Western Queensland have indicated that any direct form of pasture improvement, either in endeavours to introduce new species or by treatment of the existing pastures, would be uneconomic. This is because of the low carrying capacity of the country—1 sheep to 5.5 acres—and the low and unreliable summer rainfall.

A study of the yield and composition of Mitchell grass pasture for twelve months has supplied valuable data for the conservation of fodder in the areas concerned. We now know when the protein content of the pasture is at its maximum in relation to rainfall. This figure in conjunction with yield will enable us to cut hay at a time when a product of maximum quality will be obtained. Prior to this investigation no such figures were available for Western Queensland pastures.

A study of ram fertility in relation to pasture quality is in the early stages. It has been demonstrated that clinically normal rams possess a high degree of infertility during the hot summer months. The present experiments are an endeavour to determine whether atmospheric conditions or pasturage has the more profound effect.

III. ABSTRACTS OF RECENT PUBLICATIONS ON GRASSLAND IN AUSTRALIA

The publications enumerated in this section are arranged under five major headings, each with a number of sub-sections. Within each section the publications are arranged according to the institution at which the investigation was carried out and in the order: Commonwealth, New South Wales, Victoria, Queensland, South Australia, Western Australia and Tasmania. Authors' names are in alphabetical order for each institution. An index of authors is provided; index of genera will be found on pp. 105-107.

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ABSTRACTS

A. Pasture Ecology

1. Pedology Climatology Surveys

1 Blake, S. T. Notes on some pasture problems of Western Queensland. *Proc. roy. Soc. Qd.* 47. 89-91. 1935.

2 Blake, S. T. The plant communities of Western Queensland and their relationships with special reference to the grazing industry. *Proc. roy. Soc. Qd.* 49. 156-204. 1937. This paper discusses the soils, climate and vegetation of the greater part of pastoral Queensland. The plant associations described are illustrated by photographs and a coloured map showing the plant formations and major associations is given.

3 Everist, S. L. Some notes on the Springsure and Clermont Districts. *Qd. agric. J.* 51. 30-42. 1939. A brief survey of grazing vegetation types is reported. Notes on burning and grazing management are presented, and problems relating to invasion of undesirable grasses, soil erosion, plant poisoning and weeds are discussed.

4 Everist, S. L. Inland Pastures. Part II. Response during 1934 season of Mitchell grasses in Western and Central Queensland. *Qd. agric. J.* 43. 374-87. 1935. A discussion of the more important inland grasses and fodder plants with notes on their economic value.

5 Hirschfeld, E., and Hirschfeld, R. S. Some pasture problems of Western Queensland. *Qd. agric. J.* 46. 229-45. 1936. Field studies on Mitchell grasses and saltbushes.

6 Osborn, T. G. B. On the ecology of the vegetation of arid Australia. *Trans. Roy. Soc. S. Aust.* 49. 290. 1925. Introduction and general description of the Koonamore Reserve for the study of saltbush flora.

7 Osborn, T. G. B., and Wood, J. G. On some halophytic and non-halophytic plant communities of arid South Australia. *Trans. Roy. Soc. S. Aust.* 47. 388. 1923.

8 Osborn, T. G. B., Wood, J. G., and Paltridge, T. B. On the autecology of *Stipa nitida*, a study of a fodder grass in arid Australia. *Proc. Linn. Soc. N.S.W.* 56. 299-324. 1931. Distribution, nature of seed bed, germination conditions and reactions to grazing.

9 Osborn, T. G. B., Wood, J. G., and Paltridge, T. B. On the climate of the Koonamore Vegetation Reserve to 1931. *Proc. Linn. Soc. N.S.W.* 60. 392-427. 1935. Meteorological data over a period of five years and extensive observations on the biology, distribution and regeneration of the principal trees and shrubs of arid Australia.

10 Prescott, J. A., Davidson, J., and Trumble, H. C. Climatology in relation to biology and agriculture. *J. Aust. Inst. Agric. Sci.* 3. 77-9. 1937.

11 Richardson, A. E. V. Problems relating to the development of grassland. *J. Coun. Sci. industr. Res. Aust.* 2. 5. 1929. A discussion of the ecological, agrostological, and genetical problems involved in the improvement of grasslands in Australia.

12 Richardson, A. E. V. The improvement of grassland. *Scot. J. Agric.* 11. 249. 1928. A discussion of the scientific problems underlying grassland development in Australia.

13 Scott, R. C., and Hutton, E. M. Pasture improvement in South Australia. *J. Dept. Agric. S. Aust.* 39. 8-34. 1935. Division of the agricultural areas of the State into pasture districts according to rainfall, water supply and soil conditions, with recommendations for suitable pasture species for each type. Adequate phosphatic manuring is necessary, while subdivision of fields and systematic grazing, together with conservation of fodder, permit the carrying of a maximum number of stock.

14 Trumble, H. C. The climatic control of herbage plants in Southern Australia. *Rep. Aust. Ass. Adv. Sci.* Vol. 23. Canberra, 1939. (In press.)

15 Trumble, H. C. Some introductory principles of pasture ecology. *J. Aust. Inst. Agric. Sci.* 4. 66-70. 1938. The best approach to the pasture problem appears to be through the investigation of basic ecological factors in terms of their relationship to the behaviour of plant forms, first as individuals, then as aggregates, and finally as communities of associate forms. The main features of the pasture complex are enumerated and important considerations in the practical utilization of the relationships between herbage plants and environmental factors are discussed.

16 Trumble, H. C. The relation of pasture development to environmental factors in South Australia. *J. Dept. Agric. S. Aust.* 38. 1460-87. 1935. The main types of natural and seeded pasture in South Australia are discussed in relation to soil and climatic factors, and the location of the grazing areas and the intensity of stocking from point to point are related to climax vegetation.

The effects of top-dressing with soluble phosphates and of rainfall on natural pastures are discussed; there is a significant trend from natural to seeded pastures.

The influence of phosphatic and nitrogenous manuring on botanical changes and productivity in pastures is dealt with, and a list of pasture mixtures for specified environments is given.

17 Trumble, H. C. The development of pastures in South Australia. *Scot. geogr. Mag.* 53. 10-6. 1937. A generalized account of the main vegetation regions of South Australia, as related to climate and type of agricultural development, the main factors influencing pasture establishment, the utilization of improved herbage species, and recent trends in pasture development.

18 Trumble, H. C. The climatic control of agriculture in South Australia. *Trans. Roy. Soc. S. Aust.* 61. 41-62. 1937. The principal climatic factors affecting the distribution of crop and herbage plants in South Australia are examined and compared with the types of agriculture practised. The annual period of growth for herbage plants is largely governed by the "period of influential rainfall", which is determined from the monthly relationship between rainfall and free water evaporation. Maps showing the mean influential rainfall period in relation to wheat and pasture distribution, the amount of influential rainfall and the more important edapho-climatic zones of South Australia are included.

19 Trumble, H. C., and Donald, C. M. Soil factors in relation to the distribution of subterranean clover and some alternative legumes. *J. Aust. Inst. Agric. Sci.* 4. 206-8. 1938. Attention is drawn to certain soil factors which limit the growth of subterranean clover under climatic conditions suitable for this species. Alternative legumes such as lucerne, *Medicago tribuloides* and *M. lupulina* are recommended for highly calcareous soils.

20 Trumble, H. C., and Cornish, E. A. The influence of rainfall on the yield of natural pasture. *J. Coun. Sci. industr. Res. Aust.* 9. 19-28. 1936. The influence of annual, seasonal and monthly rainfall on the yield of unfertilized and top-dressed natural pasture for a period of ten seasons at the Waite Institute has been investigated by correlation and regression; the correlation is strongest in the period April to June inclusive, which coincides with the early stages of seasonal growth.

The effectiveness of autumnal and early winter rainfall and the relative ineffectiveness of late winter and spring rainfall in determining yield appear to be associated with the type of pasture investigated, which comprises species with a restricted growing period and a limited capacity for production.

21 Wood, J. G. The vegetation of South Australia. pp. 164. 58 figs. 9 maps. Govt. Printer. Adelaide, 1937. A description of the natural plant communities in South Australia.

21A DUNNE, T. C. Pasture development in Western Australia. 1931-1936. Muresk Agric. Coll., W. Aust. 1938. pp. 24 (mimeographed). A general review and summary of work done in Western Australia for the period 1931-36 upon (1) summer dry areas, and (2) irrigation areas respectively.

(1) The annual species, subterranean clover and drooping flowered clover [T. *cernuum*], remain the most suitable plants for forming the bases of the pasture in the areas reviewed. White clover is of definite value in the south coastal districts. The most suitable grasses for the west coastal area are *Phalaris* and perennial ryegrass, and in the south coastal belt, *Phalaris*, perennial ryegrass, cocksfoot and Yorkshire fog are all giving good results.

(2) Perennial ryegrass, *Paspalum*, and white clover are the outstanding species. Heavy rates of seeding are not necessary and cover crops not desirable. After establishment, "superphosphate only" gives the most profitable returns.

22 NICHOLS, J. E. Investigations in the pastoral areas in Western Australia. *J. Aust. Inst. Agric. Sci.* 4. 10-7. 1938. A discussion of the problem of drought fodders, their edibility, nutritive value, and utilization in the Murchison District of Western Australia.

2. Plant Introduction

23 HARTLEY, W. Pasture legumes for tropical and sub-tropical Australia. Review of present knowledge. *Herb. Rev.* 3. 9-11. 1935. While the tropical and sub-tropical pastures of Australia are on the whole seriously deficient in legumes, numerous species are present in some degree throughout most of the area. The problem of increasing the proportion of legumes consists in (1) making better use of the material available, and (2) searching for new species to supplement the existing resources. Research on pasture management and strain selection might lead to increase in legumes in northern Australian pastures.

24 MCTAGGART, A. Promising introduced grasses and legumes. Results of Queensland tests. *J. Coun. Sci. industr. Res. Aust.* 7. 161-4. 1934. The article cites and briefly discusses species of *Digitaria, Brachiaria, Ixophorus, Chloris, Eragrostis, Panicum, Amphilophis, Ischaemum, Polytrias, Pennisetum, Bromus, Festuca, Phalaris, Lespedeza, Alysicarpus*, etc., which were introduced by C.S.I.R. and which showed definite promise in tests conducted at Lawes and Lawnton, Queensland.

25 MCTAGGART, A. A study of persistence in certain introduced pasture grasses. Coun. Sci. industr. Res. Aust. Pamphlet 59. 1935. pp. 16. Data obtained systematically over 2.5 years at Duntroon (A.C.T.) from persistency trials with twenty-one recently introduced grasses are tabulated. As the result of preliminary tests, these species and strains were chosen for sward investigations because they appeared to be the most promising for differing conditions in Australia. Notes on the palatability to sheep of these grasses are presented, and the plants classified according to their varying reaction to differential sward treatment. Descriptions of various characteristics of the grasses are given. *Agropyron cristatum, A. intermedium, Brachypodium phoenicoides, Bromus inermis, B. polyanthus, Festuca Mairei, F. elatior* and *Phalaris stenoptera* are the more important grasses.

26 MCTAGGART, A. Plant introduction in relation to pasture development in Australia. *Herb. Rev.* 3. 53-6. 1935. The better known grasses and legumes introduced accidentally or otherwise since settlement began in Australia are enumerated and facts concerning their entry, adaptation, importance to the pastoral industry, etc., are stated. In general, the varying role which the large number of exotics mentioned is playing, particularly in the better rainfall areas of Australia, is set forth, together with important facts concerning many of them.

27 MCTAGGART, A. Pasture plant introduction work of the Australian Council for Scientific and Industrial Research. *Herb. Rev.* 3. 56-61. 1935. An account of the work

to date is given. Promising grasses and legumes are enumerated and facts concerning them are supplied. Particulars as to plant origin, the methods being employed for investigating their value, and concerning their apparent suitability to definite conditions are also given.

28 McTaggart, A. A study of the inter-relation of species in pasture mixtures subjected to differential treatment in the Canberra (A.C.T.) area. *J. Coun. Sci. industr. Res. Aust.* 8. 177-86. 1935. A study is made of the pasture possibilities of some sixteen mixtures and in general the suitability and inter-relation of the component individual species. Contiguous swards were subject for 2.5 years to differential grazing and mowing treatments.

Persistence of the various constituent species under the varying treatments was measured by percentage ground cover, estimated by the "point quadrat method". Palatability was gauged by noting periodically the preference of sheep for individual pasture species. The inter-relation between species is shown by means of graphs which represent fluctuations in average percentage ground cover as influenced by environmental changes plus variations in treatment.

Hawkes Bay (Old Pasture) perennial ryegrass, Akaroa cocksfoot, lucerne and sheep's burnet were the four outstanding species. Palatability and ground cover relationships are discussed.

29 McTaggart, A. Productivity in pasture mixtures subjected to differential treatment in the Canberra (A.C.T.) area. *J. Coun. Sci. industr. Res. Aust.* 9. 199-206. 1936. The paper presents tabulated data showing the average yields of air-dried forage harvested from some sixteen pasture mixtures (differentially treated) previously studied from the persistency and palatability standpoints. Mixtures which yielded most under each treatment are cited. Lucerne exerted a profound influence in increasing productivity. Akaroa cocksfoot, Hawke's Bay (Old Pasture) perennial ryegrass, tall oat grass (*Avena elatior*, L.) (where competition was not pronounced) and *Phalaris tuberosa*, in the order stated were influential in promoting productivity.

30 McTaggart, A. A study of productivity in certain introduced pasture grasses. *J. Coun. Sci. industr. Res. Aust.* 10. 17-25. 1937. The paper presents tabulated data showing the average yields of air-dried forage harvested from each of the twenty-one introduced grasses (differentially treated) which had been previously studied from the standpoint of persistency and palatability (see ref. 25).

The best yielding grasses were *Bromus polyanthus, B. arduennensis, Brachypodium phoenicoides, Agropyron intermedium* and *Festuca elatior*. Grasses which yield well, or reasonably well, in the colder portion of the year, include *Bromus polyanthus, B. arduennensis, Festuca elatior, F. Mairei, Dactylis glomerata* var. *hispanica, Phalaris coerulescens* and *P. stenoptera*. Special introduced strains of these grasses were used throughout the trial.

31 McTaggart, A. Lucerne culture—introduced varieties compared in yield with the standard variety (Hunter River) under F.C.T. conditions. *J. Coun. Sci. industr. Res. Aust.* 10. 212-15. 1937. Introduced varieties of lucerne were grown in contiguous plots at Duntroon (A.C.T.) for five years. The Hairy Peruvian introduced variety is superior in productivity to the Hunter River (check) and the Arizona Common and Chinese introduced varieties are at least equal in yield to the check. Facts concerning the history of the eight varieties tested comparatively were also stated.

32 McTaggart, A. *Stylosanthes*. *J. Coun. Sci. industr. Res. Aust.* 10. 201-3. 1937. Facts concerning the history, introduction, growth characteristics and potentialities of *Stylosanthes sundaica, S. guyannensis, S. guyannensis* var. *subviscosus* and *S. procumbens* are given. All have proved adaptable to Queensland conditions. The last three, which are perennial, were introduced by C.S.I.R. The first-named (an annual) entered Australia accidentally.

33 McTaggart, A. A study of persistency, productivity and palatability in some introduced pasture grasses. Coun. Sci. industr. Res. Aust. Pamphlet No. 77. 1938. pp.

16. Some thirty-four introduced grasses, in addition to twenty-one previously studied and reported on (see refs. 25 and 30) were systematically studied for two years at Duntroon, A.C.T., for persistency, productivity and palatability, on (a) two types of soil and under the conditions associated with (b) mowing closely every eight weeks, and (c) pasturing with sheep as growth permitted. Tabulated data show percentage ground cover, the general average of which provided an indication of persistency, and also yield of air-dry herbage. Notes based on periodic close observations representing estimated palatability, accompany the ground cover data.

The grasses so studied are classified according to (1) the most productive species and varieties, (2) the most persistent, (3) the most palatable, and (4) the types found productive, persistent and palatable at one and the same time. Under (4) are included the following: *Dactylis glomerata, Bromus inermis, Festuca varia, F. spadicea, F. pratensis, Arrhenatherum erianthum, A. avenaceum, Koeleria eriostachya* and *Danthonia semi-annularis* (check).

34 McTaggart, A. The areas of Australia in which the establishment of exotic plants is or appears to be practicable. *J. Coun. Sci. industr. Res. Aust.* 12. 151-4. 1939. On an accompanying map of Australia, isologs for a Meyer Ratio of 50, 60, 75, 100 and 150 respectively are shown. Tests of exotic plants and meteorological information are cited in support of the conclusion that the belt lying to seaward of the 75 Meyer Ratio isolog is one which, on the whole, definitely favours the establishment of exotic plants, while between that line and the 50 Meyer Ratio isolog their establishment becomes increasingly uncertain, the latter line being regarded as approximately the limit in this respect. The belt extending from the 65 M.R. isolog to the 50 M.R. isolog is considered unsuitable for the establishment of perennial exotics, but favourable for certain self-regenerating annuals.

35 McTaggart, A., Hartley, W., Paltridge, T. B., and Mair, H. K. C. Studies of five introduced grasses. Coun. Sci. industr. Res. Aust. Pamphlet 63. 1936. pp. 32. Among the numerous introduced grasses being studied by C.S.I.R., certain species are being subjected to special study. This pamphlet contains detailed information concerning five such grasses, *Agropyron intermedium, A. cristatum, Brachypodium phoenicoides, Ehrharta erecta* and *Festuca Mairei*. All the grasses described in detail, with the exception of *Ehrharta erecta*, are well suited for culture in the "Mediterranean Zone" of Australia. Data from both the botanical and pasture value standpoints are presented.

36 Leeper, G. W., Nicholls, Ann, and Wadham, S. M. Soil and pasture studies in the Mount Gellibrand area, Western District of Victoria. *Proc. Roy. Soc. Vict.* 49. Pt. 1 (New series). 77-137. 1936. The area comprises 12,000 acres between Winchelsea and Colac in a district typical of the drier belt of the Western District (annual rainfall = 22 inches). Mt. Gellibrand, 872 ft., a volcanic cone, is surrounded by a basalt plain about 400 feet above sea level. This plain is marked by characteristic stony rises giving an alternation of stony rise, rock free slope, swamp, slope, stony rise.

Nine types of soil occur due to variations in drainage, weathering of the rock and the amount of sand which had presumably been ejected with ash from the cone. Those on the rises and mountain are much more fertile than those of low slopes and swamps, as seen by the quality of the flora and the amount of organic matter. This is highly correlated with immaturity of soil, as shown by the nature of the minerals in the fine sand fractions. With lower soil types, fertility differences are due to physical causes (drainage or texture) or degree of base saturation. The only soils inherently high in fertility are too difficult to cultivate because of position. The crabhole land can grow good crops when winter is not too wet. The soils of the lower slope characterized by mineral deficiency and bad drainage tend towards pasture.

37 Miller, W. B., and Hore, H. L. Mallee wheat tests—Research Station results. *J. Dept. Agric. Vict.* 34. 505-16. 1936. Tests have been made with pasture species

introduced into the north-western Mallee district in Victoria. The most promising new species are *Ehrharta calycina* (perennial veldt grass) and *Trifolium subterraneum* (Mulwala strain) in addition to other species not commonly grown in the district, such as lucerne and *Lolium subulatum* (Wimmera ryegrass). Many species failed to survive.

38 WINDERS, C. W. Permanent summer-growing pasture grasses, legumes, etc. Qd. Dept. Agric. Stock, Div. Pl. Ind. (Research). Bull. No. 50. 1938. pp. 40. In addition to detailed descriptions of the habits and uses of the more common sown pasture plants, notes on the performance of various pasture plants introduced within recent years are given.

3. Weeds

39 CURRIE, G. A. A report on a survey of weed problems in Australia. Coun. Sci. industr. Res. Aust. Pamphlet No. 60. 1936. pp. 38.

40 CARN, K. G. Weed invasion. Its relationship to farming methods. *Agric. Gaz. N.S.W.* 48. 481-2 and 492. 1937. Specialized cropping in farming lands and indiscriminate and heavy stocking in pastoral areas have lead to the spread of introduced species until they assume serious proportions. Inedible native species have also increased where the balance of nature has been upset and useful grass species eaten out by stock.

41 CARN, K. G. Non-edible scrubs. *Agric. Gaz. N.S.W.* 49. 124-7. 1938. The question of non-edible scrubs such as turpentine (*Bertya Cunninghamii*), budda (*Eremophila Mitchelli*) and puntee (*Cassia* spp.), which are taking possession of low value pastoral lands in western New South Wales, is discussed. Conditions which encourage scrub germination and possible means of control, pulling the scrub with a horse or bullock team, firing, in the case of turpentine or grubbing with a mattock, are considered.

B. Natural Pastures

1. Regeneration

42 TWENTYMAN, R. L. The improvement of light pastures. *J. Dept. Agric. Vict.* 32. 269-72. 1934. Unimproved native pastures of Victoria consist almost entirely of gramineous species. The permanent improvement of these native pastures demands the building up of soil fertility, which can be most effectively accomplished by the introduction of *Trifolium subterraneum* and top-dressing with superphosphate. Methods for the establishment of this clover and its subsequent management are discussed.

43 WINDERS, C. W. Problems of pasture maintenance and rehabilitation in semi-arid Queensland. *Qd. Agric. J.* 45. 154-63. 1936. Data regarding the behaviour of Mitchell grasses are presented and methods of improving western pastures are suggested.

44 TRUMBLE, H. C. Preliminary investigations on the cultivation of indigenous saltbushes (*Atriplex* spp.) in an area of winter rainfall and summer drought. *J. Coun. Sci. industr. Res. Aust.* 5. 152-61. 1932. Saltbush species may be readily established from seed under field conditions, provided seeding is effected with due regard to the temperature and moisture conditions of the surface soil. *Atriplex semibaccatum* is of special value for its summer production, low water requirement, deeply penetrating root system and high content of protein, phosphorus and sodium chloride. Limitations to the use of saltbushes include susceptibility to competition, doubtful longevity and high nitrogen requirement.

45 TRUMBLE, H. C. Plant regeneration and pasture improvement under arid and semi-arid conditions in South Australia. *Herb. Rev.* 5. 151-4. 1938.

46 WOOD, J. G. Regeneration of the vegetation on the Koonamore Vegetation Reserve, 1926-1931. *Trans. Roy. Soc. S. Aust.* 60. 96-111. 1936.

2. Grazing Management

47 FRANCIS, W. D. Inland pastures, Part I. Mitchell grasses in the Warrego District. *Qd. Agric. J.* 43. 268-81. 1935. A brief field study of Mitchell grasses (*Astrebla* spp.) and other pasture species of south-western Queensland. Continuous stocking

over an extended period of years causes destruction of Mitchell grasses. Recommendations for research are made.

48 Davies, J. Griffiths, and Sim, A. H. The influence of frequency of cutting on the productivity, botanical and chemical composition and the nutritive value of " natural " pastures. Coun. Sci. industr. Res. Aust. Pamphlet 18. Melbourne, 1931. A small area of typical unmanured natural pasture was cut at intervals of 2, 4, 7, 10, and 20 weeks, for the two growing periods of 1927 and 1928. It was concluded that the severe defoliation reduced the total yield of produce materially and greatly modified the botanical composition, but that higher total yields of dry matter were obtained with decreasing frequency of cutting. The optimum return of nutrients per acre was obtained when the pasture was cut at intervals of seven weeks.

49 Osborn, T. G. B., Wood, J. G., and Paltridge, T. B. On the growth and reactions to grazing of the perennial saltbush, *Atriplex vesicarium*. An ecological study of the biotic factor. *Proc. Linn. Soc. N.S.W.* 57. 377-402. 1932. A study of the autecology of the species and the effect of different types of grazing on vigour. Intermittent, relatively heavy stocking produces the most beneficial effect.

3. Fertilizers and Renovations

50 Moodie, A. W. S. Top-dressing New England pastures. *Agric Gaz. N.S.W.* 34. 301-6. 1934.

51 Richardson, A. E. V. Top-dressing of natural pastures. *J. Dept. Agric. Vict.* 12. 12-29. 1914. Details are given of the plan of a permanent top-dressing grazing trial commenced in 1912. Remarkable increases in the growth of trefoils and clovers and in the vigour of the grasses were noted as a result of top-dressing with phosphates and lime.

52 Richardson, A. E. V. Development of grass lands. *J. Dept. Agric. Vict.* 22. 193-207 and 257-70. 1924. The deterioration of Victorian natural pastures due to overstocking and the drain of mineral nutrients is discussed. Experiments conducted at Rutherglen, Hamilton and Glenthompson have shown that the growth and carrying capacity of the top-dressed pasture has been increased to almost double that of the untreated pasture. At Rutherglen the percentage of clovers and trefoils was increased from 14.3 per cent on the unmanured to 74.8 per cent on the superphosphate 1 cwt. plots. Thirty top-dressing tests conducted at various country centres in 1923 under the auspices of the Chamber of Agriculture practically all showed substantial increases in growth on the superphosphate plots. The botanical composition of the sward and the time and rate and frequency of application are discussed.

53 Murray, J. K., Bryan, W. W., and Steele, W. G. A top-dressing experiment on the pastures of the sandy ridges of the Lockyer Valley. *Qd. Agric. J.* 48. 16-21. 1937. A poor indigenous mixed pasture, the chief constituents of which were *Fimbristylis dyphylla*, 22 per cent, *Bothriochloa decipiens*, 20 per cent, *Eragrostis elongata*, 10 per cent, and *Eremochloa bimaculata*, 10 per cent, deficient in legumes (less than 1 per cent total) was top-dressed with a series of artificial manures. Botanical analyses were made by the estimated percentage area method, and cuttings were taken to estimate total yield and yield of nitrogen and phosphorus. Nitrogen and phosphate in combination was the only treatment to give an increase, this increase being of the order of 40 per cent in the yield taken over the two peak months of midsummer. There was no increase in the percentage of nitrogen or phosphate in the forage. At the time of observation, no changes in botanical composition were noticeable. The carrying capacity of these pastures is too low to justify the expense of even small dressings of artificial manures.

54 Cook, L. J. Annual report on pasture work, Kybybolite, 1934-35. *J. Dept. Agric. S. Aust.* 39. 765-9. 1936. The manuring of natural pasture.

55 Cook, L. J. The development of Red Gum

Lands. *J. Dept. Agric. S. Aust.* 40. 638-41. 1937. The manuring of natural pasture.

56 DAVIES, J. GRIFFITHS, FRASER, K. M., and SCOTT, A. E. Natural pastures: their response to superphosphate. Coun. Sci. industr. Res. Aust. Bull. 83. 1934. pp. 76. Investigations were conducted at the Waite Institute and at the Experimental Farm, Kybybolite, to ascertain the effect of phosphatic fertilizers on carrying capacity, nutritive value and mineral content of natural pastures in the better rainfall areas of South Australia. Merino wethers were maintained exclusively on the pastures throughout four seasons, and were weighed at periodic intervals. The weight and quality of the wool produced by the sheep, and the changes in the yield and botanical composition of the grazed pastures were also determined. At each centre the carrying capacity of the natural pasture was materially increased by the application of superphosphate, but no important differences were observed in the mean live-weight or the quantity or quality of the wool produced by each sheep as a result of top-dressing with phosphate. The sheep fluctuated markedly in live weight with the period of the season. The application of superphosphate produced marked changes in the botanical and chemical composition of the pasture.

57 TRUMBLE, H. C., and FRASER, K. M. The effect of top-dressing with artificial fertilizers on the annual yield, botanical composition and carrying capacity of a natural pasture over a period of seven years. *J. Dept. Agric. S. Aust.* 35. 1341-53. 1932.

4. Conservation

58 TWENTYMAN, R. L. Conserving meadow hay. *J. Dept. Agric. Vict.* 31. 584-9. 1933. The necessity for conserving surplus spring pasture growth is stressed. The methods applicable for Victorian conditions and the effect of grass hay cutting on the pasture are discussed.

5. Productivity, Nutritive Value

59 DAVIES, J. GRIFFITHS, SCOTT, A. E., and KENNEDY, J. F. The yield and composition of a Mitchell grass pasture for a period of twelve months. *J. Coun. Sci. industr. Res. Aust.* 11. 127-39. 1938. A maximum yield equivalent to one ton hay per acre was obtained, with growth active from January to April, but thereafter practically negligible. Rapid deterioration in yield and composition occurred from April to September. Phosphorus and protein became very low by September, and phosphorus was definitely inadequate for the maintenance of adult sheep from June onwards. Low calcium, in all cuts, was associated with a deficiency of legumes in the pasture.

60 RICHARDSON, A. E. V. The mineral content of pastures. Progress Report on co-operative investigations at Waite Agricultural Research Institute. Coun. Sci. industr. Res. Aust. Pamphlet No. 17. 1930. pp. 29.

61 RICHARDSON, A. E. V. The mineral content of pastures. Report on co-operative investigations in progress at Waite Agricultural Research Institute. *J. Coun. Sci. industr. Res. Aust.* 5. 141-51. 1932.

62 RICHARDSON, A. E. V. The effect of climate on the composition of pasture plants. *Herb. Rev.* 1. 96-9. 1933. The protein and mineral content of pastures from tropical and subtropical areas are generally lower than of pastures in cold temperature regions. Apart from the known influence of species, growth stage, soil type and fertilizers on the composition of pastures, it is possible that the explanation may be found in terms of difference in the effect of the two contrasting types of climate on the uptake of nitrogen-phosphorus and minerals on the one hand, and the assimilation of carbon on the other, the carbon-nitrogen ratio tending to be high in tropical climates and low in temperate climates.

63 BECK, A. B., and LAPSLEY, R. G. The composition of capeweed (*Cryptostemma calendulaceum*) from Meckering and Beverley. *J.*

Dept. Agric. W. Aust. 15. 422-6. 1938. The nutritive value of capeweed, which occurs commonly in stubble pastures, is discussed in the light of the results of chemical analyses. Pastures of pure capeweed contain a large amount of water (up to 92 per cent), but, considering the dry matter alone, it is for the greater part of the season a high quality feed. There is a high protein content in the early growth and the percentages of calcium, sodium and potassium are also high. Phosphorus is low, judged by overseas standards. High water content gives the capeweed a low feeding value in the green state.

64 Beck, A. B., and Underwood, E. J. The composition of some grasses from Turee Creek Station of the north-west pastoral area of Western Australia. *J. Dept. Agric. W. Aust.* 15. 55-60. 1938. Analyses are given of several native grasses, from material collected at various times during the year. The grasses are in general low in protein, calcium and phosphorus, and high in fibre. The fibre content tends to place the grasses on a level with straw rather than hay or pasture herbage. The quality of the better grasses (*Astrebla pectinata* and *Eragrostis Brownii*) approximates to poor quality wheaten hay.

C. Sown Pastures

1. Establishment

65 Riceman, D. S., and Cashmore, A. B. Improved pastures in the Clare District, South Australia—Investigation to determine suitable introduced species for use in that area. *J. Coun. Sci. industr. Res. Aust.* 12. 144-50. 1939. A species trial was made at Anama Station, near Clare, South Australia, over the three-year period 1935-1937, to determine the most productive pasture mixture for that area and the best mixture to compete with Cape tulip (*Homeria collina*). Wimmera ryegrass was the most productive and also the most severe in competition with associated plants and weeds. In the third season, however, higher yields of total herbage were obtained from *Phalaris tuberosa* and perennial ryegrass swards established with the early Dwalganup strain of subterranean clover than from the Wimmera ryegrass plots. It is doubtful whether perennial ryegrass or midseason Mt. Barker subterranean clover will persist at Anama Station. The seed-mixture recommended for use in this habitat is: *Phalaris tuberosa* 3 lb., early subterranean clover 5 lb. per acre. Pastures established so far have given a high level of production of total herbage. No information is yet available to suggest that the establishment of sown pastures will lead to the control of Cape tulip on infested country, although this must be considered a possibility.

66 Moodie, A. W. S. Sowing lucerne with wheat. *Agric. Gaz. N.S.W.* 419-23. 1936.

67 O'Reilly, M. V. Lucerne "inoculation." An essential to successful establishment on lighter soil types. *Agric. Gaz. N.S.W.* 48. 549-53. 1937.

68 Whittet, J. N. Light seedings of pasture plants. *Agric. Gaz. N.S.W.* 49. 183-8. 1938.

69 Anon. Pasture trials at Camperdown. Progress Report. *J. Dept. Agric. Vict.* 31. 426-8. 1933. The Victorian old pasture and New Zealand certified perennial ryegrass strains have developed good persistent swards. *Phalaris tuberosa* promises to establish successfully in competition with perennial ryegrass. Late sown pasture was not as severely checked by Cape weed (*Cryptostemma calendulaceum*) as that sown earlier.

70 Cherry, T. Improvement of Victorian pastures. *J. Dept. Agric. Vict.* 4. 493-7. 1906. Pasture trials involving surface harrowing, top-dressing with artificial fertilizers and light seeding showed good responses to phosphatic fertilizers, and the stock showed a preference for the phosphate-treated pasture. Top-dressing with 1 cwt. superphosphate per acre for eight years increased the feed fourfold as compared with untreated land. Top-dressing with superphosphate is advocated for steep hill country of Gippsland.

71 Colebatch, W. J. Culture of permanent pastures. *J. Dept. Agric. Vict.* 6. 655-65.

1906. The desirability of sowing pastures with productive introduced species instead of permitting volunteer "tumbledown" grasses to take possession of the land is emphasized. Thorough preparation of the seed bed and the sowing of a grass-clover mixture are advocated. Much of the pasture seed on the Victorian market has a very low germination. Dung or farmyard manure gives the best results on grassland, but artificial fertilizers may be necessary in Victoria. A dressing of 5 to 10 cwt. lime, 2 cwt. Thomas phosphate and 2 cwt kainit per acre is necessary at seeding. The pasture is harrowed in the autumn to distribute stock droppings.

72 HARRISON, J. E. Improving pastures in sheep areas. *J. Dept. Agric. Vict.* 34. 325-7. 1936. Subterranean clover combined with top-dressing with superphosphate has increased the number of sheep in the State 40 per cent in the last 10 years. *Lolium perenne* is a good associate grass with subterranean clover in districts of over 23 inch average annual rainfall, while Wimmera ryegrass and *Phalaris tuberosa* are preferable in drier areas.

73 HARRISON, J. E. The sowing and management of pastures. *J. Dept. Agric. Vict.* 34. 273-7. 1936. Autumn seeding of pastures is advocated except in areas where late rains are frequent, when spring sowings may be adopted. Seed is sown on a clean, fine seed bed after the first rains have germinated the weeds which are destroyed by harrowing. The seed may be sown either on a cultivated crop or with an oat cover crop. The young pasture is lightly grazed in the first year.

74 HARRISON, J. E. Permanent pasture mixtures. *J. Dept. Agric. Vict.* 34. 376-80. 1936. The strong competitive growth of perennial ryegrass in a seeds mixture is stressed. Weed control in the first season can be effected by the inclusion of a cheaper short-lived ryegrass, which would permit a stronger development of the sown clovers in the second year.

75 HARRISON, J. E. Permanent pasture mixtures. *J. Dept. Agric. Vict.* 34. 521-8 1936. Various pasture seeds mixtures. suitable for the establishment of permanent and temporary pastures under different soil and climatic conditions in Victoria are given. The suitability of the various strains for Victorian conditions is discussed.

76 HARRISON, J. E. Subterranean clover. *J. Dept. Agric. Vict.* 35. 77-84. 1937. The soil, fertilizer and grazing requirements of subterranean clover are discussed. Early autumn seeding gives the best results—4 lb. seed per acre being advocated. Of eighty-two seed samples examined, 41 per cent contained more than 20 per cent hard seed, some samples containing over 50 per cent. The methods of harvesting seed are outlined.

77 KING, J. W. Experiments with grasses and fodder plants. *J. Dept. Agric. Vict.* 2. 538-40. 1903. Species trials including thirty-five varieties of pasture and fodder plants were laid down in 1902. The species varied greatly in their ability to flourish under the conditions provided, the best being *Dactylis glomerata, Bromus uniolotdes, Festuca elatior, Paspalum dilatatum, Trifolium hybridum,* and *Poterium sanguisorba.*

78 MILLER, W. B., GOULDING, C. P. and MORROW, J. A. Results of pasture investigations at the Rutherglen Experiment Farm. *J. Dept. Agric. Vict.* 34. 578-83. 1936.

79 MULLETT, H. A. Subterranean clover. *J. Dept. Agric. Vict.* 20. 760. 1922. Subterranean clover is particularly adapted for improving carrying capacity where soil and climatic conditions do not permit of the satisfactory development of English grasses and clovers. The plant is best established by means of a cover crop, and top-dressing with superphosphate is essential for good growth.

80 TWENTYMAN, R. L. Pasture improvement investigations. *J. Dept. Agric. Vict.* 31. 235-7. 1933; 32. 172-202. 1934; 33. 209-19. 231-44. and 260. 1935; 34. 1-4. and 18. 1936; 35. 173-94. 217-26. 229, 1937; and 36. 157-70. 197-204. 214-24. 1938. These reports of work conducted by the Victorian Department of Agriculture under arrangement with the Victorian Pas-

ture Improvement League represent the results of a comprehensive series of trials throughout the State.

81 Victorian Department of Agriculture. Pasture investigations—Second Annual Report. *J. Dept. Agric. Vict.* 32. 172-202. 1934. Results are given of the first two years' experimental work by the Department of Agriculture for the Victorian Pasture Improvement League. Eleven complete "major" trials and thirty-five "Pilot plots" embracing grazing, mowing, manurial and species trials have been established.

82 Victorian Department of Agriculture. Pasture investigations—Third Annual Report. *J. Dept. Agric. Vict.* 33. 209-19. 1935. Excellent responses to top-dressing with superphosphate have been obtained. Responses have been most marked on the light soils and during the early spring period. Nitrogenous fertilizers have given a poor response where the pastures contain a good proportion of clover, but a marked response has been recorded on a pasture consisting of almost pure ryegrass. An increasing response to potash is recorded on mowing trials at Larpent and Cobrico. Tables are given showing the relative vigour of the various grass and clover species on the Gippsland and Western District trials of sown species.

83 Victorian Department of Agriculture. Pasture investigations—Fourth Annual Report. *J. Dept. Agric. Vict.* 34. 172-92. 1936. The progress of the trials and the survival and growth of the species during 1935 are recorded. Superphosphate continues to give good responses on the pilot plots and rotational grazing areas, but potash is now becoming a limiting factor on the mowing manurial areas. Lime in addition to superphosphate has effected a good response in Gippsland; in the Western District lime has not been effective, but potash is assuming increasing importance. New trials are planned to test these responses further. *Lolium perenne* is the outstanding perennial grass, both the Hawkes Bay and the local Victorian old pasture strain giving excellent results. Sown alone, the ryegrass has not made satisfactory headway, but has grown well in combination with clovers.

84 Victorian Department of Agriculture. Pasture investigations—Fifth Annual Report. *J. Dept. Agric. Vict.* 35. 173-94 and 217-26. 1937. Results largely confirm those of previous years. Under the mowing treatment, the need for potash is yearly becoming greater. New plots established at Colac and Cobden have shown marked responses to potash. Charts are given showing seasonal growth and total annual production from the variously manured plots.

85 Victorian Department of Agriculture. Pasture investigations—Sixth Annual Report. *J. Dept. Agric. Vict.* 36. 157-70 and 214-24. 1938. The seasonal growth of a number of Victorian pastures is shown by graphs. The influence of New Zealand practices on Victorian pastures is discussed. Fertilizers trials subjected to repeated mowings show a declining response where superphosphate alone is applied, but where potash is applied with the superphosphate the good response is sustained. Rock phosphate has shown a good prolonged response in the wetter districts. Trials with surface establishment of subterranean clover have shown that both severe working and heavy applications of superphosphate in the first year encourage undesirable annual grasses at the expense of the native grass which it is usually desired to retain. This work has been extended to the irrigated pasture area of the North and to the dry pastures of the North-East.

86 Anon. A note on fodder crop experiments at Meringa Sugar Experiment Station. *Cane Growers' Quart. Bull.* 5. 134-7. 1938. Reprinted in *Qd. Agric. J.* 49. 456-9. 1938. Early results of trials of soybeans, lespedezas, clovers and grasses. Soybeans, *Panicum maximum* and *Echinochloa crus-galli* were satisfactory in the first year.

87 McBryde, D. L. Sheep grazing at the Mackay Experiment Station. *Cane Growers' Quart. Bull.* 5. 1-3. 1937. Reprinted in *Qd. Agric. J.* 48. 136-7. 1937. An experiment to determine the value of the Mackay Sugar cane lands for pasture production has been commenced.

88 McBryde, D. L. and Kerr, H. W. Sheep

grazing and fat lamb raising at Mackay. *Cane Growers' Quart. Bull.* 6. 12-4. 1938. Reprinted *Qd. Agric. J.* 50. 206-9. 1938. A sugar cane pasture rotation is in progress. It is hoped to improve the cane soils and at the same time to raise sheep and lambs on the pasture.

89 Quodling, H. C. Reclaiming prickly-pear land. *Qd. Agric. J.* 34. 513-24. 1930. Experiments were made in laying down pastures on rotting prickly-pear mulch following destruction of the pest by *Cactoblastis cactorum*. The season was very favourable, and satisfactory establishment of some species was secured.

90 Skinner, A. F. Some observations on the establishment and management of pastures on the tropical coast. *Qd. Agric. J.* 50. 164-71. 1938. A description is given of those methods of establishing and managing pastures which have proved practical and economical. *Brachiaria mutica, Melinis minutiflora* and *Panicum maximum* are noted as the chief cultivated grasses. The utility of subdivision and rotational grazing has been demonstrated.

91 Winders, C. W. Annual summer-growing pasture grasses and fodder crops. *Qd. Dept. Agric. Stock. Div. Plant Ind.* (*Res.*) Pamphlet. No. 51. pp. 11. 1938. Sudan grass, sorghums, maize, "millets," *Panicum* spp. *Setaria* spp., cowpea, velvet bean and peanut for grazing and fodder purposes.

92 Winders, C. W. Winter-growing pasture grasses, legumes and fodder crops. *Qd. Dept. Agric. Stock. Div. Plant Ind* (*Res.*) Pamphlet No. 52. pp. 26. 1938. Winter-growing pasture plants contribute only to a small extent to the pasture resources of Queensland. The winter cereals offer the best means of providing winter green feed. Descriptions are given of the various species of pasture grasses, legumes and fodders in use, embodying the results of trials over a period of years. *Phalaris tuberosa* is a promising permanent grass, while Wimmera ryegrass and *Bromus unioloides* are useful in some areas. Perennial ryegrass and cocksfoot are not of great value. White clover is naturalized in some coastal districts.

93 Hill, R. An analysis of pasture development in South Australia. *J. Dept. Agric. S. Aust.* 42. 250-9. 1939. The State has made progress in establishing improved pastures, but has not reached the same efficiency in pasture management and animal husbandry to make the best use of these pastures.

94 Scott, R. C. Pasture experiment, Ungarra. *J. Dept. Agric. S. Aust.* 40. 620. 1937. Wimmera ryegrass and lucerne yielded good feed, but Dwalganup subterranean clover has not persisted satisfactorily.

95 Scott, R. C. Pasture varieties, Copeville. *J. Dept. Agric. S. Aust.* 40. 624. 1937. Wimmera ryegrass, lucerne and creeping saltbush (*Atriplex semibaccatum*) did well and are useful fodders for the district. Perennial ryegrass, *Phalaris tuberosa, Trifolium glomeratum* and *Danthonia pilosa* failed.

96 Trumble, H. C., Donald, C. M., Smith, C. A., and Strong, T. H. The establishment of pastures on deep sands in the upper south-east of South Australia. Coun. Sci. industr. Res. Aust. Bull. 122. pp. 24. 1938. A mixture of lucerne and *Phalaris tuberosa*, sown without a cover crop, or a mixture of lucerne, early flowering subterranean clover and Wimmera ryegrass, sown with the first, second or third cereal crop are satisfactory combinations for pasture establishment on the mallee-heath areas of Upper South-east of South Australia. In newly-developed areas, lucerne should be artificially inoculated with an effective strain of *Rhizobium*, and annual dressings of at least 1.5 cwt. superphosphate per acre are recommended. In general, lightly sown cereal crops do not affect the yield of seeded legumes, but seriously reduce seeded grasses. Leguminous cover crops reduce the yield of herbage legumes but not of grasses to any great extent.

97 Trumble, H. C. and Davies, J. Griffiths. The role of pasture species in regions of winter rainfall and summer drought. *J. Coun. Sci. industr. Res. Aust.* 4. 140-51. 1931. A discussion of the herbage species suitable for the "Mediterranean" climatic regions in South Australia. Three distinct

habitats are recognized, based mainly on their water relationships. The improvement of pastures within each belt is primarily determined by the species occurring in the pastures, and the improvement of soil fertility and methods of pasture management cannot find full expression without the replacement of the annual non-legumes by perennial herbage plants. It is concluded that the most promising herbage species are *Phalaris tuberosa*, *Lolium perenne*, Wimmera ryegrass, *Danthonia* spp., *Ehrharta calycina*, *Trifolium subterraneum*, *Medicago sativa*, *Atriplex semibaccatum*, with, in addition, *Dactylis glomerata*, *Trifolium repens* and *T. pratense* for irrigated pastures.

98 Baron-Hay, G. K. Pasture nursery plot. *J. Dept. Agric. W. Aust.* 12. 190-2. 1935. Perennial ryegrass may be planted on soils of high fertility which retain summer moisture, or are irrigated. *Phalaris tuberosa* should be sown on a well-prepared seed-bed reasonably free of weeds, as severe weed competition during its first year may cause a complete failure. White clover in those areas where *Sminthurus viridis* and *Penthaleus destructor* are severe should not be sown in autumn, or a complete failure may result.

99 Dunne, T. C. Seeding experiments with first early "Dwalganup" subterranean clover. *J. Dept. Agric. W. Aust.* 13. 67-9. 1936. Best results obtained with seedings 0.25 inch deep and 0.5 inch deep where seventy-seven and seventy-five plants respectively appeared from a hundred seeds. Sowings at 1 inch were satisfactory, at 1.5 inch the results were poor, and 2 inch sowings were a failure. No plants were obtained from seeds dropped on the surface. The results showed the need for shallow planting and the necessity for covering the seed. Heavier sowings than 4 lb. per acre would be unprofitable for pasture establishment. Under the conditions of the experiment, 4 lb. per acre was the most profitable rate of seeding.

100 Dunne, T. C. and Gibsone, H. K. Development of perennial ryegrass plants as affected by rate of seeding. *J. Dept. Agric. W. Aust.* 14. 113-5. 1938. An experiment with perennial ryegrass and white clover pastures indicated that the heavy rates of seeding of pasture seeds prevalent in more temperate countries were unsuitable. Investigations of plots sown at rates of 4, 8 and 16 lb. of perennial ryegrass per acre showed that better developed plants were obtained with the lighter seedings. The number of tillers produced on all plots was approximately equal. The most grazing was obtained from plots seeded at 8 lb. per acre.

101 Elliott, H. G. Trials with pasture and fodder species conducted at the Denmark Research Station. *J. Dept. Agric. W. Aust.* 15. 245-8. 1938. Of the fodder plants, the "Bell Windsor" variety of horse bean was outstanding. The estimated yield of seed per acre was 60 bushels. *Lathyrus annuus* and *L. langitanus* were the most promising of the other species.

102 Bevin, R. H. and Fricke, E. F. Recent research on pasture mixtures and grazing management. *Tasm. J. Agric.* 8. 112-7. 1937.

2. Grazing Management

103 Harrison, J. E. Pasture management. *J. Dept. Agric. Vict.* 29. 317-20. 1931. Advises the resowing of the old cultivated or outlying paddocks of the farm and their regular annual top-dressing. On the better pastures nearer the homestead, greater attention should be given to subdivision, rotational grazing, mowing and harrowing.

104 Twentyman, R. L. Winter growth of pastures. *J. Dept. Agric. Vict.* 30. 118-22. 1932. The fluctuations in seasonal growth of Victorian pastures are discussed and methods suggested for stimulating growth during the lean winter period. Top-dressing and the introduction of subterranean clover, the maintenance of soil fertility and harrowing to spread animal droppings are advocated.

105 Twentyman, R. L. Seasonal growth of Victorian pastures. *J. Dept. Agric. Vict.* 33. 53-62. 1935. Using weighed cuttings taken at frequent intervals by lawn mowers, seasonal growth curves have been

constructed for typical Victorian dairying pastures. The influence of artificial and particularly nitrogenous fertilizers on this seasonal growth has been studied. Approximately 70 per cent of the annual growth is made during the three spring months. As a result of the general increase of soil fertility by repeated top-dressings with superphosphate, winter growth may be improved but fertilizers have not been effective in increasing growth during summer drought. Nitrogenous fertilizers promoted increased growth in the late autumn and early spring periods, but the response was of short duration and was followed by a prolonged period of depressed growth.

106 Winders, C. W. Sown pastures and their management. Qd. Dept. Agric. Stock, Div. Plant Ind. (Res.), Pamphlet No. 49. pp.28. 1938. Also in *Qd. Agric. J.* 48. 6-15, 119-135, 258-280, 414-429, 567-596, and 679-691. 1937. This pamphlet discusses the most important pasture grasses and legumes and forage crops for use in Queensland. Sections are also devoted to seed quality, strain values, soil fertility requirements, preparation of seed-bed, methods of sowing and planting, pasture management and pasture top-dressing.

107 Cook, L. J. Raising export lambs on subterranean clover pasture lands. *J. Dept. Agric. S. Aust.* 39. 1124-34. 1936. Results of three seasons' work on the raising of export lambs from Comeback ewes by various British breeds of rams, using flocks of forty-four ewes mated to single sires, and reared wholly on subterranean clover pasture. 105 per cent of lambs were marketed from ewes that bred, with average live weight of 73.5 lb. on the farm and average dressed weight of 30.6 lb. at the Portland Freezers, 105 miles distant. 61 per cent were classified as first quality, 34.5 per cent as second quality, 3.7 per cent as third quality, and less than 1 per cent rejected. The net return was 15s. 6d. per lamb at Kybybolite. On allowance for losses and grazing cost, flock mated to Dorset Horn ram returned 13s. 11½d. per ewe, that to Southdown ram 13s. 10d., that to Suffolk 13s. 7½d., that to Ryeland 12s. 10¾d. and that to English Leicester ram 12s. 5½d.

108 Cook, L. J. *Phalaris tuberosa* and strawberry clover pasture mixture. *J. Dept. Agric. S. Aust.* 42. 414-5. 1939. The sheep grazing results obtained by rotationally grazing four small fields of two acres, each to be 7.04 sheep per acre over a 399 day period.

109 Richardson, A. E. V., Trumble, H. C. and Shapter, R. E. The influence of growth stage and frequency of cutting on the yield and composition of a perennial grass—*Phalaris tuberosa*. Coun. Sci. industr. Res. Aust. Bull. 66. 1932. pp.35. Growth stage was found to exercise a determining influence on the protein, crude fibre, carbohydrate and mineral content. A downward migration occurred of portions of the nitrogen and phosphate of the herbage to the basal portion of the stem and to the root system. A substantial and absolute loss occurred from all parts of the plant, including the herbage, basal internodes, and root system during the final stage of growth. A migration of potash to the soil amounted to 27.8 per cent of the total intake by the plant. The effect of various systems of defoliation on the yield, protein and phosphorus content of the plant was investigated.

110 Bevin, R. H. and Sherwin, R. A. Rotational grazing trial in St. Mary's District. *Tasm. J. Agric.* 1. 167-70. 1930; 2. 167-70. 1931; 4. 171-4. 1933. Subdivision, surface cultivation, annual top-dressing with 1 cwt. superphosphate, improved drainage and intensive grazing with dairy cattle on run-out pastures consisting primarily of *Agrostis tenuis* and *Holcus lanatus* resulted in an increased carrying capacity and a production increase of over 100 per cent. There was a general improvement in the composition and condition of the sward.

3. Fertilizers and renovation

111 Moore, R. M. Renovation of grazing lucerne. *Agric. Gaz. N.S.W.* 48. 245-6. 1938. The cultivation of a grazing lucerne stand at Bathurst in a dry year (17 inches annual rainfall) is of great benefit. The experiment does not show whether the same results would be obtained under higher rainfall conditions or with lucerne used solely for cutting and not subjected to soil compaction by stock.

112 Anon. Pasture top-dressing tests. *J. Dept. Agric. Vict.* 28. 476-80. 1930. Manurial trials conducted at Cavendish, Warncoort, Mooroodne, during 1926-29 showed substantial increases in growth where the pasture had been top-dressed with 1 or 2 cwt. superphosphate per acre. Neither lime, potash or sulphate of ammonia when applied in addition showed any benefit.

113 Anon. Pasture improvement. *Qd. Agric. J.* 37. 246-7 and 314. 1932. Experiments on paspalum renovation and sowing of winter-growing grasses and clovers.

114 Anon. Pasture improvement. *Qd. Agric. J.* 442-5. 1935. The first annual report of the Second Pasture Improvement Committee states that winter pasture trials and paspalum renovation and manurial experiments are being conducted.

115 Andrew, W. D. Pasture top-dressing. *J. Dept. Agric. Vict.* 33. 191-3. 1935. Superphosphate containing 22 per cent phosphoric acid (P_2O_5) is the most effective fertilizer for top-dressing Victorian grassland. Nitrogenous fertilizers have not given satisfactory results. Potash and lime have effected an improvement in only a few cases.

116 Batchelor, J. E. Pasture deficiencies. *J. Dept. Agric. Vict.* 2. 541-4. 1903. Stock grazing upon stubble lands which had been manured with superphosphate thrive better than those on untreated areas.

117 Coleman, F. F. Intensive pasture management—I. *Qd. Agric. J.* 36. 603-5. 1931. Results are presented of a paspalum pasture top-dressing trial at Runcorn, near Brisbane. No response to phosphatic manures was obtained. Animals preferred portions treated with nitrogenous fertilizers.

118 Coleman, F. F. Pasture improvement in Queensland. A year's work at Maleny. *Fertilizer* 17. 173-5. 1932. A description of a one year's manurial trial on old paspalum-clover pastures.

119 McFadzean, J. J. Top-dressing pasture land. *J. Dept. Agric. Vict.* 18. 408-12. 1920. Good results were obtained on several farms from top-dressing pastures with superphosphate. Strawberry clover, widespread in the district, has responded strongly to the treatment.

120 Miller, W. B. and Morrow, J. A. Sheep carrying capacity and top-dressing. *J. Dept. Agric. Vict.* 32. 499-502. 1934. Grazing trials at the Rutherglen Experiment Farm over a 14 year period showed a 70 per cent increase in carrying capacity of pasture treated first at yearly and then at four-yearly periods, with 1 cwt. superphosphate per acre. Subterranean clover pastures treated annually with 0.5 cwt. superphosphate per acre carry from 2.5 to 3 sheep per acre, unimproved native grass pastures less than one sheep per acre. The repeated use of superphosphate has encouraged the growth of annual exotic grasses, mainly *Festuca myuros, Bromus* spp. and *Hordeum murinum*. On an established subterranean clover pasture, a dressing of 1 cwt. superphosphate showed a 58 per cent increase in growth in the first year and a residual response of 24 per cent in the second.

121 Mullett, H. A. Pasture top-dressing. *J. Dept. Agric. Vict.* 24. 385-90. 1926. Good results were obtained from superphosphate on native and sown pastures in the better rainfall areas of the State. Over a number of experiments the average increase in growth for a 1 cwt. dressing was 50 per cent while 2 cwt. dressings doubled production. At Hamilton, a 2 cwt. dressing continued to exert a beneficial residual effect for five years. Grazing trials at Bannockburn showed that top-dressing with 1 cwt. superphosphate per acre gave an increase of 9.5 lb. wool per acre.

122 Mullett, H. A. Pasture management—top-dressing with artificial fertilizers. *J. Dept. Agric. Vict.* 29. 160-9. 1931. The results of departmental pasture top-dressing trials at six centres are given. Good responses were obtained from superphosphate, applications resulting in a greater proportion of clovers and trefoils and a marked increase in feeding value of the herbage. Other fertilizers have not shown a profitable return.

123 Murphy, E. W. Treatment of pastures—prevention of rickets, cripples and paralysis. *J. Dept. Agric. Vict.* 15. 449-56. 1917. Instances quoted where the disease "cripples" has been overcome by top-dressing pastures with phosphate. Bone meal is claimed to give better results than superphosphate.

124 Penman, F. Note of available nitrogen in pasture soils. *J. Dept. Agric. Vict.* 29. 439-43. 1931. The response of a pasture to nitrogenous fertilizers is in inverse proportion to the amount of ammoniacal nitrogen in the soil. Evidence suggests that for soils more alkaline than pH 6.0, nitrate nitrogen values will be important.

125 Twentyman, R. L. Response of Victorian pastures to potash. *J. Aust. Inst. Agric. Sci.* 4. 210-2. 1938. Mowing manurial pasture trials commenced in 1932 showed good response to superphosphate and little response to potash during the first years. As these trials proceeded, potash assumed increasing importance, and on many of the areas the stage has been reached where only small responses to superphosphate can be obtained unless potash is applied in addition.

126 Winders, C. W. Renovation of *Paspalum* pastures. *Qd. Agric. J.* 49. 5-9. 1938. Methods of renovating paspalum pastures by the use of tine and pick implements, ploughing, and rotation of pastures and crops are described. Definite recommendations regarding top-dressing of paspalum pastures cannot yet be made for the major soil types.

127 Hill, R. Development of our hills country. *J. Dept. Agric. S. Aust.* 39. 180-1. 1935. Shows the increases in livestock and their production in Adelaide, Sturt and Hindmarsh counties, and attributes the main factors responsible for the increases to superphosphate and subterranean clover, coupled with the subdivision of pastures into smaller fields.

128 Scott, R. C. Top-dressing pasture land. *J. Dept. Agric. S. Aust.* 40. 776-8. 1937. Phosphorus is the one plant food universally lacking in South Australian soils; consequently the manuring of pastures in this State consists almost invariably of the application of phosphatic fertilizers, of which superphosphate is the cheapest and most convenient form. Dressings heavier than the average for the State, namely 113 lb. per acre, are distinctly remunerative. At least 2 cwt. per acre can be applied in sown pasture areas of the South-East and Adelaide Hills, increasing to 3 cwt. for the higher-producing flats and swamp lands of the State.

129 Trumble, H. C. and Donald, C. M. The relation of phosphate to the development of seeded pastures on a podsolized sand. Progress report on co-operative investigations at the Waite Agric. Res. Inst. Coun. Sci. industr. Res. Aust. Bull. 116. pp. 47. 1938. Mixed pasture was attained rapidly on a virgin podsol as a result of liberal phosphate application in conjunction with subterranean clover and a light seeding of *Phalaris tuberosa*; no other fertilizer than phosphate was necessary. Dry matter production followed the well-known Mitscherlich relationship, but phosphate recovery was directly proportional to the effective phosphate dressing, and the nitrogen return per cwt. of superphosphate applied decreased less rapidly than the total yield, as the fertilizer dressing was increased. The development of the associate grass rose markedly as the phosphate dressing increased; this depended upon previous accumulation of nitrogen in the early part of the season, but later in the season phosphate assumed a major role in determining the further development of the grass complement. The dressings of superphosphate normally employed can be considerably increased before maximum economic returns are likely to be realized.

130 Bevin, R. H. Economic aspect of top-dressing. *Tasm. J. Agric.* 2. 1-4. 1931; 3. 36-9. 1932 and 4. 77-9. 1933. The effect of top-dressing of natural pastures, sown pastures and natural pasture upon which subterranean clover had been surface-introduced was measured by means of sheep carrying capacity. Results showed the economic advantage of superphosphate on all three classes of pasture.

131 Sherwin, R. A. Pasture top-dressing trials in midlands. *Tasm. J. Agric.* 6. 87-9. 1935.

132 Sherwin, R. A. and Fricke, E. F. Pasture top-dressing trials in midlands. *Tasm. J. Agric.* 9. 177-80. 1938. Established subterranean clover pasture was top-dressed with superphosphate at the rate of 1, 2, 3 and 4 cwt. per acre. Results showed the advantage of 2 cwt. dressings in the first two years and of 1 cwt. dressings in subsequent years.

4. Productivity, Nutritive Value

133 Clunies-Ross, I., Chamberlin, W. E. and Turner, Helen Newton. The influence of improvement of pastures and rotational grazing on parasitism, body weight and fleece production in crossbred sheep in Tasmania. *J. Coun. Sci. industr. Res. Aust.* 10. 313-26. 1937.

134 Clunies-Ross, I., Graham, N. P. H., Turner, Helen Newton, Carter, H. B. and Muntz, H. The grazing of sheep on improved pastures. Its effect on superfine wool. Coun. Sci. industr. Res. Aust. Pamphlet No. 71. 1937. pp. 24. A comparison was made between comparable groups of sheep maintained for twelve months on improved (subterranean clover) pastures at the rate of three sheep per acre, and on natural pasture at the rate of one sheep per acre. Wool production per acre on improved pasture was 33.36 lb. compared with 8.92 lb. on natural pasture. Wool grown by the improved pasture group was longer in staple and gave as high a clean scoured yield as that grown on natural pasture. The wool of the improved pasture group was 70/74's count with a much smaller percentage of 70's than the other group. Microscopic examination of the wool fibre of young sheep maintained on improved pasture throughout showed no tendency for the wool to become stronger, but for the fibre diameter to be maintained or even to become slightly finer. Parasitic infestation in both groups was controlled by two drenches administered in the summer and autumn. Following these the sheep on improved pasture showed a lesser degree of infestation for the four winter months than those on natural pasture.

135 Bulcock, F. W. Cattle fattening on coastal pastures. Objects and results of Tully Experiments. *Qd. Agric. J.* 49. 460-8. 1938. The progress of investigations into a scheme for fattening on tropical pastures of beef cattle brought from native pastures away from the seaboard. Preliminary observations indicate the suitability of pastures of *Brachiaria mutica, Melinis minutiflora* and *Panicum maximum* for fattening purposes.

136 Richardson, A. E. V. Mineral deficiencies in pastures. *J. Coun. Sci. industr. Res. Aust.* 1. 92. 1927. Memorandum prepared for the Imperial Agricultural Research Council (1927), outlining proposed co-operative investigations on pastures.

137 Richardson, A. E. V., Trumble, H. C. and Shapter, R. E. Factors affecting the mineral content of pastures. Coun. Sci. industr. Res. Aust. Bull. 49. 1931. pp. 47. Pure species grown under similar soil conditions and harvested at a definite growth stage showed wide differences in mineral and nitrogen content, mineral accumulation in relation to transpiration, and absorption of phosphorus from insoluble phosphate. Growth stage was found to exercise a determining influence on the nitrogen and mineral content of pasture species. Nitrogen assimilation and absorption of essential nutrients are most active at the tillering stage; photosynthesis rises to a maximum shortly after the flowering stage, while transpiration losses are greatest during the final stages of growth. The composition of the plant is affected by the differences in the soil fertility. The application of soluble phosphate to phosphate-deficient soils increases the phosphorus content of the herbage. The supply of minerals in a pasture can be increased by the establishment of suitable species, the utilization of the herbage by appropriate methods of pasture management, and the maintenance of soil fertility with suitable fertilizers.

138 Shapter, R. E. The chemical composition of certain pasture species at flowering and

maturity. *J. Coun. Sci. industr. Res. Aust.* 8. 187-94. 1935. Chemical composition of twenty characteristic species of pasture plants, including eleven grasses, four legumes, and five miscellaneous species, grown under identical cultural conditions in pots was recorded. Wide variations were shown to occur between the species within each group. Soluble ash values were not characteristic for any of the groups; the quantities over-lapped from one group to another. In contradistinction to this the legumes had very low insoluble ash contents compared with grasses, both in leaf, stem and in seed. Two species of *Hordeum* gave lower values for ether extract in seed than in leaf and stem. Seeds of legumes were considerably richer in ether extract than seeds of most of the grasses, but *Phalaris minor* gave a remarkably high value (7.6 per cent). *Trifolium subterraneum* was prominent among the legumes with 15.16 per cent. The seeds all showed high concentrations of phosphorus, and *P. minor* was again prominent among the grasses, with 1.12 per cent (P_2O_5). *Erodium botrys* among the miscellaneous species was outstanding in that its contents of nitrogen and phosphorus were similar to those in legumes; its soluble ash was the highest recorded. The seed, however, was not especially rich in nitrogen, and had a medium phosphorus content.

139 Underwood, E. J., Shier, F. L. and Harvey, R. J. Investigations into the composition of Western Australian Wheat Belt pastures and stubbles. *J. Dept. Agric. W. Aust.* 14. 442-6. 1937. A study of the pastures in three areas typical of the Western Australian Wheat Belt has been made over a two-year period.

The outstanding features of these pastures were their low productivity and their low protein content for about 8 to 9 months of the year. The phosphorus content of the herbage was also low for most of the year. The calcium figure remained exceptionally high, however, in almost every case. The low productivity and the low phosphorus content are associated primarily with the long dry period. The almost entire absence of any good quality, productive pasture legume is thought, however, to be a strong contributory factor.

D. Irrigated Pastures

1. Establishment

140 Bartels, L. C. The irrigation of pasture lands. *J. Dept. Agric. Vict.* 25. 160-5. 1927. Sown mixed pastures are superior to lucerne for grazing purposes in irrigation districts. The necessity for grading and checkbanking the land to permit the proper application of water is emphasized. The effect of rate and time of application of irrigation water is discussed.

141 Bartels, L. C. Irrigated pastures. *J. Dept. Agric. Vict.* 26. 111-8. 1928. Details given as to the methods of preparation of the land prior to seeding for permanent irrigated pastures. The suitability of the various pastures species and the subsequent grazing and management of the pastures are discussed.

142 Bartels, L. C. Irrigated pastures—Establishment and management hints. *J. Dept. Agric. Vict.* 29. 66-9. 1931. Records a rapid extension in the area of sown pasture in the irrigated districts of the State. Attention is drawn to the necessity for careful preparation of the land for seeding, effective watering, top-dressing and efficient grazing.

143 Mullett, H. A. Systematic pasture management. *J. Dept. Agric. Vict.* 29. 11-3. 1931. Attention is drawn to the superior feeding value of the short pasture growth. The possibilities of the adoption of the Hohenheim system of intensive rotational grazing under Victorian conditions are discussed.

144 Trumble, H. C. and Davies, J. Griffiths. The establishment, persistency and productivity of selected pasture species on an irrigated reclaimed swamp. Coun. Sci. industr. Res. Aust. Bull 80. 1934. pp. 32. Preliminary and exploratory investigations were made over a period of 89 weeks to determine the most suitable pasture species, strains and mixtures for an irrigated reclaimed swamp. It was concluded that a simple seeds mixture of truly permanent strains of perennial ryegrass, cocksfoot, white clover and red clover was particularly suitable. A mixture of *Phalaris tuberosa, Poa pratensis* and white

clover also gave good results. The yields of certain mixtures were approximately double those of the best perennial ryegrass swards, and 77 per cent greater than that of lucerne. Relatively low seed rates proved satisfactory.

145 Baron-Hay, G. K. and Elliott, H. G. Pasture development. *J. Dept. Agric. W. Aust.* 13. 55-63. 1936; 14. 36-49. 1937; 15. 109-19. 1938. For the establishment of irrigated pastures, rapid growing cover crops such as Sudan grass and Japanese millet are detrimental to the initial establishment of *Trifolium repens* and, to a much less degree, *Paspalum*. If *Cynodon dactylon* is present prior to seeding, cover crops will definitely assist its spread to the detriment of the sown species. Therefore, rapid growing cover crops cannot be recommended when establishing permanent pastures under irrigation. Results have indicated that up to 6 cwt. superphosphate per acre per annum are profitable, and that at least 4 cwt. should be applied annually in 2 to 4 applications. A heavy rate per acre should be applied in the autumn. Superphosphate and ammonia mixtures are profitable only as an initial application at the time of planting, and at least 2 cwt. of a 3 to 1 mixture should be applied per acre. If properly managed, the following seed mixtures (in lb. per acre) can be sown under irrigated conditions:—(1) *Paspalum dilatatum* 8, perennial ryegrass 4 and white clover 2; (2) perennial ryegrass 6, cocksfoot 3 and white clover 2. Spring planting of the pasture is recommended in every case. Conclusive results are not available from the grass species trial under irrigated conditions.

146 Dunne, T. C. and Gibsone, H. K. Comparison of autumn and spring sowing of irrigated pastures. *J. Dept. Agric. W. Aust.* 13. 383-7. 1936. It would appear that, providing the conditions are not unduly unfavourable, a satisfactory stand of ryegrass may be secured by planting in autumn or in spring. *Sminthurus viridis* and *Penthaleus destructor* often cause considerable damage to young clover plants. These pests are usually more troublesome with the autumn than with the spring planting. Recommendations for planting are given.

2. Grazing Management

147 Bartels, L. C. Irrigated pastures—hints on management. *J. Dept. Agric. Vict.* 31. 590-3. 1933. Pastures are assuming increasing importance in irrigation areas. Suitable species and desirable manurial and management treatments for permanent pastures under irrigation are indicated. In districts where the water supply is uncertain, good results are being obtained from Wimmera ryegrass and subterranean clover.

148 Bartels, L. C. Irrigated pastures—intensive grazing tests with sheep. *J. Dept. Agric. Vict.* 33. 261-6. 1935. Commencing in 1930, the two halves, A and B, of 10 acres of uniform irrigated pasture were subdivided respectively into two and ten small paddocks. Each half was rotationally grazed with sheep, the plots in group A being grazed 10 days and rested 10 days, while the plots in B were grazed 2 days and rested 18 days. The average yearly live weight increase per acre on A was 703 lb. and on B 776 lb. The productivity of the pasture did not decline during the trial, and ewes lambed successfully during the fourth and fifth years.

149 Beruldsen, E. T. Irrigated pastures—factors in management. *J. Dept. Agric. Vict.* 26. 718-21. 1928. The necessity for care in the preparation of the land for sowing and the importance of top-dressing and proper grazing methods are stressed.

150 Beruldsen, E. T. Inland pastures—probable effects of the adverse season. *J. Dept. Agric. Vict.* 36. 591-3. 1938. The shortage of irrigation water should emphasize the need for its more economical use. The proper laying out of paddocks and the keeping of supply channels clean and free from obstructions are necessary to avoid wastage. Four inch waterings, liberal use of superphosphate and the avoidance of overgrazing will increase the return per unit of water. Light waterings are uneconomical, while waterings in excess of 4 inches are wasteful.

151 Beruldsen, E. T. and Morgan, A. Irrigated

pastures—influence of grazing. *J. Dept. Agric. Vict.* 32. 440-5. 1934. An acre area of irrigated pasture reserved for horse-grazing was charted at three-monthly intervals, the unit areas being classified as heavily, moderately and lightly grazed. The general outline of the neglected patches remained constant throughout the period. Small areas composed of annual grasses did, as a result of seasonal growth, vary from a moderately grazed to a neglected condition.

152 Beruldsen, E. T. and Morgan, A. Irrigated pastures—the effects of spelling for varying periods. *J. Dept. Agric. Vict.* 34. 99-108. 1936. The influence of the interval between grazings on the yield and botanical composition of an irrigated permanent pasture was determined. There was a progressive increase in total yield as the interval between mowings was lengthened up to 8 weeks. The production of grasses increased and legumes decreased as the time between cuts increased. Frequent cutting favoured white and strawberry clovers but adversely affected the red clover. During the spring the pasture was grass-dominant, but became clover-dominant during the summer and early autumn. A positive correlation was established between the protein percentage and the rate of production of dry matter. The periods of the maximum and minimum production of the various components of the swards were determined.

153 Beruldsen, E. T. and Morgan, A. Irrigated pastures—rotational grazing. *J. Dept. Agric. Vict.* 35. 94-102. 1937. During the period May 1931 to May 1932 an area of 10 acres of irrigated pastures subdivided and rotationally grazed carried an average of 14.8 sheep per acre and gave an average live weight increase of 563 lb. per acre. The amount of herbage consumed by the sheep was estimated by means of yield sampling. Cold weather depressed the daily consumption of herbage. The methods of estimation used are discussed.

154 Beruldsen, E. T. and Morgan, A. Irrigated pastures—influence of grazing. *J. Dept. Agric. Vict.* 36. 60-7. 1938. On a pasture grazed entirely by horses, never more than 50 per cent of the herbage was effectively grazed. The position of the neglected patches did not alter materially over a period of years. The ungrazed patches were dominantly grassy and all horse droppings were concentrated in these areas. A cattle pasture was dunged indiscriminately and there was little permanency in the relative positions of short and long patches. Sheep are very efficient grazers but care must be taken to prevent excessive defoliation, which weakens the pasture.

155 Mullett, H. A. Pasture management—principles of controlled grazing. *J. Dept. Agric. Vict.* 29. 116-20. 1931. A policy of sub-division and rotational grazing of pasture is advocated to permit efficient grazing of herbage when at a stage of maximum food value. The adoption of this method at Werribee has increased the carrying capacity of an irrigated pasture from 6 to 13 sheep per acre.

156 Richardson, A. E. V. Investigations on irrigated pastures: (1) The yield and botanical composition of an irrigated permanent pasture under various systems of pasture management. Coun. Sci. industr. Res. Aust. Bull. 71. 1932. A seeded pasture, established under irrigated conditions on a typical reclaimed swamp area, was highly productive under rotational grazing by sheep. Monthly cuts gave a total yield of 8.7 tons dry matter per acre during the season following establishment, and averaged over 25 per cent protein and 1 per cent phosphoric acid. The yield of herbage was 30 per cent greater under rotational grazing at 28-day intervals than under cutting at similar intervals. This increase was attributed mainly to the substantial return of nutrients, in the form of animal excrement, under grazing conditions. A good balance of ryegrass and clover was maintained under rotational grazing. Under mowing, however, the pasture rapidly became clover-dominant. Mowing at 56-day intervals gave a 31 per cent higher total yield and a more suitable feed for fattening sheep than mowing at 28-day intervals. The mean carrying capacity of 70 acres of permanent pasture over a period of 12 months was 16.2 sheep per acre.

3. Fertilizers and Watering

157 Anon. Irrigation investigations—irrigated grasses. *J. Dept. Agric. Vict.* 28. 560-4. 1930. Irrigated permanent pastures at Werribee show an increasing response to dressings of from 1 to 4 cwt. superphosphate per acre. Lime, gypsum, potash and nitrogenous fertilizers did not increase total yields. The irrigated pastures produced three times the annual yield of the non-irrigated pasture.

158 Bartels, L. C., Beruldsen, E. T. and Morgan, A. Irrigated pastures—rate and frequency of watering tests. *J. Dept. Agric. Vict.* 30. 187-205. 1932. The yields of herbage from permanent pasture receiving various rates and frequencies of watering are shown by tables and graphs. The contributions made by the various species on the different plot swards are shown. Best results were obtained with a seasonal irrigation of six waterings of four inches. Perennial ryegrass was favoured by frequent waterings in excess of four inches, while the proportion of cocksfoot increased with six waterings of three inches. With frequent waterings of four inches, the white clover assumed dominance over subterranean clover.

159 Bartels, L. C., Beruldsen, E. T. and Morgan, A. Irrigated pastures—results of manurial trials. *J. Dept. Agric. Vict.* 31. 86-100. 1933. From a standpoint of total yield, superphosphate is pre-eminent as a fertilizer for irrigated pastures of which the main constituents are perennial ryegrass, cocksfoot and white clover. Under the watering system employed, the limit of profitable application of superphosphate had not been reached with a 4 cwt. per acre dressing. The efficacy of the phosphatic manures is determined by their readily available P_2O_5 content. The P_2O_5 annually removed from the "No Manure" plots was responsible for a declining yield from these plots. Neither lime nor nitrogenous fertilizers effected any improvement in yield.

Effect on Botanical Composition. All phosphatic manures, particularly superphosphate, raised the productivity of the four major species—ryegrass, cocksfoot, white clover, and subterranean clover. Nitrate of soda, ammonium sulphate and potassium sulphate slightly lowered the production of white and subterranean clovers and raised the production of ryegrass and cocksfoot.

Effect on Chemical Composition. The comparatively high protein contents, low fibre figures and narrow nutritional ratios indicated that the herbage, as mowed from all plots, was immature. Variations in composition which appeared from cut to cut appeared to be due to variation in the production rate of the pasture. Phosphatic manures increased the protein content and feeding value, the increase being proportional to the available P_2O_5 content of the manure used. Nitrogenous manures depressed the protein content and widened the nutritive ratio accordingly. Potassium sulphate had no appreciable effect. Compared with 2 cwt. superphosphate, all combinations of 2 cwt. superphosphate and nitrogen, potash, lime and gypsum depressed the protein content and produced herbage of inferior feeding value.

160 Beruldsen, E. T. and Morgan, A. Irrigated pastures—rate and frequency of watering tests. *J. Dept. Agric. Vict.* 33. 67-74. 1935. A description is given of the difficulties and of the method of yield sampling grazing trials developed at the State Research Farm, Werribee. Tables are given showing the amount and chemical composition of the herbage consumed by sheep. The sheep selectively grazed the leafy protein-rich portion of the herbage. The greatest production of herbage was obtained with six waterings of 4 inches.

161 Morgan, A. Species in irrigated pastures—controlling factors. *J. Dept. Agric. Vict.* 31. 261-5. 1933. The influence of watering, grazing and manurial treatment on the composition of irrigated pastures at Werribee is discussed. The efficiency of the summer watering of the pasture controls the proportion of the inferior winter-growing annual species which appear in the sward.

162 Baron-Hay, G. K. and Elliott, H. G. Fertilizer trials on irrigated pastures under controlled grazing. *J. Dept. Agric. W. Aust.* 13. 63-6. 1936. Sulphate of am-

monia is not profitable; until further information is available, at least 2 cwt. superphosphate should be used, and superphosphate only should be used.

4. Productivity. Nutritive Value

163 Beruldsen, E. T. and Morgan, A. Irrigated pastures—the effects of spelling for varying periods. *J. Dept. Agric. Vict.* 34. 99-108. 1936. There were progressive increases in yield from the weekly to the 8-weekly cuts; those cut for hay in November and then cut every three weeks show a decrease in yield as compared with 8-weekly cut plots. Frequent cutting resulted in a clover dominance in the sward; the production of the grasses rose with increasing intervals between cuts; the production of the legumes was in general inversely affected, although there was very little difference between weekly, fortnightly, 3-weekly and monthly plots. A well-balanced herbage was obtained on the plots cut at monthly or 5-weekly intervals. Ash and protein percentages diminished and fibre percentage rose as time between cuts increased, a well-balanced chemical composition being achieved in the clippings from plots cut monthly or 5-weekly.

164 Gallus, H. P. C. Investigations on irrigated pastures. (2) The chemical composition of irrigated pastures at Wood's Point, South Australia. Coun. Sci. industr. Res. Aust. Bull. 71. 1932. pp. 45. The nitrogen and phosphoric acid content of irrigated pasture is high throughout the year. Changes in yield and botanical composition caused by mowing instead of grazing are accompanied by changes in chemical composition. Mowing at 56-day intervals instead of 28-day intervals lowers the percentage of nitrogen and phosphoric acid. Pasture cut at 56-day intervals showed the lowest protein, ether extract and ash, and highest fibre and N-free extract.

165 Jewell, W. R. Chemical studies of pasture. *J. Dept. Agric. Vict.* 29. 357-61. 1931. The effect of rate and frequency of watering on chemical composition and nutritive value of frequently-cut samples of irrigated mixed pastures. When cut frequently, the herbage is rich in protein and mineral content and remains constant, irrespective of watering treatment.

E. Special Problems

1. Species, strains, selection and breeding of herbage plants

166 Hubbard, C. E. The genus *Astrebla* or Mitchell Grasses. *Kew Bull.* 257-66. 1928. The early nomenclature of the genus is discussed, and, briefly, its utility from a pastoral viewpoint. A generic description is given, together with a key to and detailed description of the four species.

167 McMillan, J. R. A. Hybridization of subterranean clover (*Trifolium subterraneum* Linn.). *J. Coun. Sci. industr. Res. Aust.* 10. 167-8. 1937. A technique for the hybridization of subterranean clover.

168 Dwyer, R. E. P. Lucerne breeding. *Agric. Gaz. N.S.W.* 42. 49-52. 1931. With the rapid extension of lucerne growing into different climatic and soil conditions, a definite need has arisen for the development of types and strains adapted to these conditions. The close observation of lucerne fields readily reveals marked variations between individual plants in habit, leafiness, type and vigour of growth, etc., and the aim of the breeder is to secure a strain which will uniformly reproduce the type and vigour of the best plants in such a field. Selection in self-fertilized lines is regarded as the basis of improvement, and the experience with this method at the Bathurst Experiment Farm during the past three or four years is given.

169 Dwyer, R. E. P. Seed setting in lucerne. *Agric. Gaz. N.S.W.* 42. 703-8. 1931. Observations on the controlling factors in seed setting are discussed with a summary of the present knowledge, together with some recent observations by the writer. The importance of seed setting in lucerne to the commercial grower and the relation of seed setting to lucerne improvement are discussed.

170 Dwyer, R. E. P. Brief notes on seed setting in lucerne. Imp. Bur. Plant Genetics: Herbage

Plants. Bull. No. 7. 32-3. 1932. A contribution to the technique employed in the breeding of herbage and forage plants.

171 Dwyer, R. E. P. New technique in lucerne breeding. *Herb. Rev.* 1. 135-6. 1933.

172 Dwyer, R. E. P. Lucerne breeding. *Herb. Rev.* 4. 1-8. 1936.

173 Dwyer, R. E. P. and Allman, S. L. Further observations on pollination and seed setting in lucerne. *Agric. Gaz. N.S.W.* 43. 141-6. 1932. Since it is of considerable moment to the plant breeder to determine what agencies may effect self- or cross-pollination, investigations at Bathurst have been designed to provide further information. Although natural crossing of lucerne is known to occur, the exact extent and agencies involved are still doubtful. The main tension of the keel of the flower is concentrated in the curved staminal column. A well-developed vascular system occurs in the wings of the flower petals. In the field the application of heat causes automatic tripping. The same result is obtained by dipping the flowers in alcohol. In the laboratory, under varying conditions of humidity, flowers tripped readily at temperatures ranging from 100° to 108°F. These temperatures are frequently exceeded in direct sunlight during the summer months at Bathurst. Pollen is scattered for a considerable distance following mechanical tripping. Wind is very likely to increase this radius of spread considerably. Pollen was frequently observed on the standards of untripped flowers, and was found to germinate readily. Rain is considered unimportant from the standpoint of assisting pollination, especially as excessive moisture inhibits pollen germination. Delayed tripping, with exposure of the anthers, was noted both in the open and under cages. Various miscellaneous agencies play some part by the mechanical tripping and dispersal of pollen.

174 Dwyer, R. E. P. and Allman, S. L. Honey bees in relation to lucerne seed setting. *Agric. Gaz. N.S.W.* 44. 363-71. 1933. A wide diversity of opinion exists with regard to the ability of the honey bee to trip lucerne flowers or to influence seed production. Individual bees have been observed under Bathurst conditions to trip up to 64.71 per cent of the flowers visited. As a result of a caging experiment, the honey bee was definitely proved to be capable of tripping a large percentage of flowers and influencing the amount of seed actually formed. Seed from the cage containing the bees was of better quality and more abundant than that obtained under natural conditions, which may be largely owing to the influence of more efficient cross-pollination, due to increased honey bee activity. Practically no seed was formed in cages without bees. The importance of climatic and environmental conditions and the physiological conditions of the plant must not be overlooked, and the efficiency of the honey bee may vary according to suitability or otherwise of these contions. Where investigators have failed to observe this tripping of lucerne by honey bees, this does not constitute absolute proof that such tripping is not possible. It indicates rather that the flowers were not in a suitable physiological condition, and so were not susceptible to tripping by honey bees. The experiences of a number of successful local seed growers are detailed with reference to the activities of honey bees and their ability to increase the commercial seed crop under local conditions. Results indicate the necessity for providing sufficient hives of honey bees in close proximity to lucerne seed areas.

175 Wenholz, H. Plant breeding in New South Wales. Various Science Bulletins from 1928 to 1938. Annual progress of improvement work with pasture plants.

176 Drake, F. R. Perennial ryegrass—Strain investigations in Victoria. *J. Dept. Agric. Vict.* 30. 557-64. 1932. Tests of various strains of local and imported ryegrasses revealed the superiority of the New Zealand certified and Victoria old pasture seed. The presence of some inferior lines among the Victorian samples indicates the necessity for distinguishing between seed from old pastures and inferior seed samples.

177 Drake, F. R. The principal strains of pas-

ture seeds. *J. Dept. Agric. Vict.* 31. 209-13. 1933. The origin and characteristics of the various strains of perennial ryegrass, cocksfoot, white and subterranean clovers marketed in Victoria.

178 HARRISON, J. E. Pasture plant research work at Burnley. *J. Dept. Agric. Vict.* 30. 505-11. 1930. Strain investigations are being made with Wimmera ryegrass, perennial ryegrass, cocksfoot, subterranean clover and white clover. The local strains of pasture plants have shown considerable variation and a number of the more promising strains have been isolated.

179 HARRISON, J. E. Camperdown Pasture Trials. *J. Dept. Agric. Vict.* 30. 313-5. 1932. A test of local and imported strains of ryegrass demonstrated the superior persistence and sward-forming ability of the New Zealand certified and Victorian old pasture seed. The false perennial types made rapid growth and were eagerly grazed in the first year, but they failed to survive the dry summer period.

180 HARRISON, J. E. Pasture plant research. Work at Burnley. *J. Dept. Agric. Vict.* 31. 541-7. 1933. The testing of various strains of grasses and clovers is described. Numerous local strains of subterranean clover have been isolated, and classified as early, mid-season and late strains.

181 HARRISON, J. E. Tallarook subterranean clover. *J. Dept. Agric. Vict.* 34. 135-6. 1936. Tallarook subterranean clover, a late-maturing type producing a high proportion of leaf to stem, has for the past few years bred true and grown strongly at Burnley. This strain is worthy of trial in the areas of more favourable rainfall. Seed is now being harvested and is available in commercial quantities.

182 HARRISON, J. E. Subterranean clover. *J. Dept. Agric. Vict.* 34. 609-14. 1936. The history of subterranean clover in Victoria is outlined. It is now widely distributed in this State between the 20 inch isohyet and the coast. The plant is grown as a pure stand or in association with grasses for pasture purposes. Hay yields may vary from one to three tons per acre. From 250 to 300 lb. of seed may be produced per acre in 25-inch rainfall districts. The possibility of harrowing the burr to the surface in order to provide summer grazing is suggested.

183 HARRISON, J. E. Seed certification—Conditions of scheme. *J. Dept. Agric. Vict.* 35. 119-23. 1937.

184 HARRISON, J. E. Subterranean clover—Strains. *J. Dept. Agric. Vict.* 35. 77-84. 365-70. 1937. More than forty distinct strains of subterranean clover have been recognized and isolated at the Burnley Research Station. These have since been grown without loss of type, or evidence of interpollination. A fairly close relationship exists between the character of the strain and the environment in which it has developed.

185 BLAKE, S. T. The Genus *Iseilema* in Queensland. *Proc. Roy. Soc. Qd.* 49. 82-94. 1937. Extensive collecting during 1936 made possible considerable work on the systematics of *Iseilema* and relationships between species. Two new species are described, two more hybrids are indicated, and a key to all new forms included.

186 COLEMAN, F. F. Pasture improvement. *Qd. Agric. J.* 37. 314-7. 1932. The first year's results of species and strain trials at Lawnton, near Brisbane.

187 CASHMORE, A. B. An investigation of the taxonomic and agricultural characters of the *Danthonia* group. Coun. Sci. industr. Res. Aust. Bull. 69. 1932. pp. 23. The grouping of *Danthonia* species is undesirable, owing to the individuality of the specific groups. Considerable strain variation exists, and types of superior agronomic value have been isolated. The extended production period of *Danthonia* is well suited for wool production.

188 CASHMORE, A. B. A comparative study of *Lolium perenne* and *Phalaris tuberosa* at varying stages of growth. Coun. Sci. industr. Res. Aust. Bull. 81. 1934. pp.28. Perennial ryegrass was more vigorous in establishment than *Phalaris tuberosa*, out-

yielding the latter in the first year by more than 100 per cent. In the second year the ryegrass was no more vigorous than in the first year, and was considerably outyielded by *Phalaris*. Root penetration in *Lolium perenne* reached 52 inches in both seasons; *Phalaris* penetrated to 76 inches in the first season and 91 inches in the second season. Suppression of *Phalaris* by *Lolium* in the first season was attributed to root competition in the surface layers of soil. Under the Adelaide environment, *L. perenne* is the more rapidly establishing and aggressive species; once establishment has been effected, however, *P. tuberosa* is the more persistent and productive species.

189 Donald, C. M. Strain variation in strawberry clover (*Trifolium fragiferum* L.) and prairie grass (*Bromus unioloides* H.B. et K.). *J. Aust. Inst. Agric. Sci.* 2. 122-3. 1936. Investigations with a view to strain selection and improvement have been commenced with these two species. Fifty seed samples of *Bromus* species, including 29 of prairie grass, were sown as single plants at the Waite Institute, and under irrigation at Wood's Point, in 1935. Similar work was commenced with 24 samples of strawberry clover. Much variation was evident between the different lines of both species. As in each case the species is normally self-fertilized, it is hoped that within a comparatively short period strains will be available which are superior to the available commercial types.

190 Donald, C. M., and Smith, C. A. Neal. Strain variation in subterranean clover (*Trifolium subterraneum* L.). *J. Coun. Sci. industr. Res. Aust.* 10. 277-90. 1937. The yield, leafiness and flowers per plant in strains of this species were all found to be highly and positively correlated with lateness of maturity. The number of seeds per raceme was closely dependent upon the rate of evaporation during the flowering period. The Tallarook variety set seed more freely than other types under adverse climatic conditions. The bearing of the work on choice of variety, mixing of varieties, origin of types and development of commercial strains is discussed.

191 Hill, R. Subterranean clover—its history in South Australia. *J. Dept. Agric. S. Aust.* 40. 322-30. 1936. First noted in 1889 by the late Mr. A. W. Howard. First sale of seed recorded in 1906 at 2s. 6d. per lb. Top-dressing with fertilizers was recorded by Mr. Howard in 1908. Statistical figures show that 5 cwt. seed were collected in 1916, and the industry came into prominence in 1923-4, when 807 cwt. of seed were harvested. By 1934-35, 240 tons were harvested from 1,768 acres. Mechanical methods of harvesting are shown.

192 Hill, R. Yorkshire fog grass. *J. Dept. Agric. S. Aust.* 41. 790-1. 1937. Value and possibilities of *Holcus lanatus* as a useful pasture species.

193 Trumble, H. C. The improvement of *Phalaris* species by selective breeding. Imp. Bur. Plant Genet. Herbage Plants. Bull. 7. 1932. pp. 33. [see p. 17]. Little ecotypical selection appears to have occurred in *Phalaris tuberosa*, and the unit for strain building has been the single plant. Plants are selected on the basis of their own characteristics, and on the performance of their selfed and out-crossed progeny. The objective of selection has been increased leafiness, density and vigour, with a high degree of adaptability to sward conditions.

194 Trumble, H. C. The agricultural features of *Phalaris tuberosa* and allied forms. *J. Agric. S. Aust.* 37. 400-25. 1934. The principal features of *Phalaris tuberosa* are its capacity for production during autumn and winter, its drought resistance, stability, adaptability to widely varying soil types and varying conditions of management, and its capacity to grow in association with subterranean clover. This grass is highly sensitive to competition, particularly from the ryegrasses during the year of establishment. The structure and depth of penetration of the root system are important in relation to both drought resistance and susceptibility to competition during the first year. The drought resistance of *Phalaris tuberosa* is not associated with a low transpiration rate, but appears to be governed by its deep rooting habit and a capacity to enter a condition

of anabiosis prior to the onset of dry conditions. Associated with these features is the close coincidence of the plant's life-cycle with the periodicity of the Mediterranean type of climate.

195 Trumble, H. C. A note on the origin of "Toowoomba Canary Grass" (*Phalaris tuberosa* L). *J. Coun. Sci. industr. Res. Aust.* 8. 195-202. 1935. The available literature relating to the origin of this grass has been reviewed and its early history interpreted. It is concluded that the grass was introduced under the name "*Phalaris commutata*" and that it originated in Italy. Botanical and agronomic examination indicate that the grass is the same taxonomically as *P. tuberosa* L. but is greatly superior for agricultural purposes to those forms of the species which have been obtained direct from Mediterranean countries.

196 Trumble, H. C. and Cashmore, A. B. The variety concept in relation to *Phalaris tuberosa* and allied forms. *Herb. Rev.* 2. 1. 1934. The forms of *Phalaris tuberosa* grown in Australia originated from a limited quantity of material grown at Toowoomba prior to 1904. Little ecological selection has occurred owing to the limited original material, a short time interval, poor capacity for regeneration from seed and persistence and adaptability of the single plant. On the other hand, Mediterranean material shows differences according to origin and has proved inferior to the cultivated Australian forms. Strain production has proceeded on the basis of single plant selection and the inter-pollination of selected parental types.

2. Seed Production

197 Whittet, J. N. Pasture seed certification. *Agric. Gaz. N.S.W.* 47. 605-7. 1936.

198 Cameron, E. D. Harvesting pasture seeds. *J. Dept. Agric. Vict.* 30. 526-30. 1932. The unreliability of the present commercial pasture seeds suggests the desirability of farmers harvesting their own seed. Methods of harvesting pasture species in Victoria are indicated.

199 Drake, F. R. The ryegrasses. *J. Dept. Agric. Vict.* 29. 573-7. 1931. The types of ryegrass commonly found in Victoria are described. Much of the ryegrass imported from New Zealand is of short-lived nature unsuited for the sowing of permanent pastures. Victorian seed harvested from old pastures is of a superior type but it is often mixed with inferior seed before being sold. The necessity for a certification scheme for this perennial ryegrass seed is indicated.

200 Harrison, J. E. "Hard Seeds" in subterranean clover. *J. Dept. Agric. Vict.* 29. 287-8. 1931. The proportion of hard seeds in subterranean clover samples may be as high as 90 per cent. The hard seeds in a sample may be readily detected by their failure to swell when soaked in water. Abrasion or chemical treatment of the hard seeds will enable germination to occur.

201 Scott, R. C. The importance of good pasture seed. *J. Dept. Agric. S. Aust.* 40. 842-3. 1937. The importance of sowing only good pasture seed cannot be over-stressed. A plant yielding an abundance of leafy material palatable to livestock occupies very little additional land to one possessing spreading habits and producing coarse stemmy growth of low feeding value. On the other hand, the former yields a greater amount of fodder per unit area.

202 Trumble, H. C. A note on *Danthonia*, with particular reference to the effect of sulphuric acid on the germination of the seed. *J. Dept. Agric. S. Aust.* 30. 1210-3. 1927. Poor and retarded germination in *Danthonia* was due to obstruction of the coleorhiza by the flowering glume, and this was overcome by treatment with 1.84 sulphuric acid.

203 Trumble, H. C. The identification of *Phalaris tuberosa* (syn. *bulbosa*) and *Phalaris minor* in seed samples and in the field. *J. Dept. Agric. S. Aust.* 34. 38-44. 1930. Attention is drawn to confusion between *P. tuberosa* and *P. minor*, and methods for identification, including a seedling root-tip test for *P. minor*, are described.

204 Trumble, H. C. Some factors affecting the

germination and growth of herbage plants in South Australia. *J. Dept. Agric. S. Aust.* 40. 779-86. 1937. Factors controlling the early development from seed of the more important pasture grasses and legumes under South Australian conditions are analysed, and the influence of temperature, seed permeability, phosphate supply and competition on the establishment and early growth of these plants in pastures is discussed.

205 Trumble, H. C. and Phipps, I. F. The inheritance of fluorescence in hybrids between perennial ryegrass and Wimmera ryegrass. *J. Coun. Sci. industr. Res. Aust.* 6. 170-8. 1933. The evidence presented indicated that: (1) fluorescence is inherited as a dominant character dependent upon one and possibly two genetic factors giving 3 : 1 and 9 : 7 ratios respectively; (2) there is no intimate relation between fluorescence of seedling and annual habit. It is argued that, since Wimmera ryegrass is doubtless of recent hybrid origin and is a mixture of many and diverse types, there is no justification for the botanical equivalents which have been applied.

206 Meadley, G. R. W. Impermeable seeds of "Dwalganup" subterranean clover. *J. Dept. Agric. W. Aust.* 13. 313-20. 1936. The significance of hard seeds is discussed. The following factors, with their possibilities of influencing the hard seed content of commercial Dwalganup subterranean clover seed, are considered: (a) climatic conditions during growing period; (b) the age of the pasture and time since previous gatherings; (c) time of gathering; (d) machinery for hulling and grading; (e) weather conditions at time of threshing; (f) size of seed; (g) storage. The most practical method of reducing the hard seed content is by scarification with machines of the so-called "decoater" type.

3. Soil erosion, Soil fertility

207 Australian and New Zealand Association for the Advancement of Science. Canberra Meeting, January, 1939. Section K. Abstracts of the following papers, presented at a discussion on Soil Erosion, will appear in the Report of the Twenty-Fourth Meeting of the Association, Vol. 24 (in press).

Russell, Sir E. John—Soil conservation and permanent agriculture.

Holmes, J. Macdonald.—The artificial stimulation of soil erosion.

Ratcliffe, F. N.—Erosion in arid areas.

Prescott, J. A.—Soil type in relation to erosion.

McDonald, A. H. E.—The erosion problem and mode of attack.

Wood, J. G.—Regeneration of plants in the arid eroded areas.

Lane-Poole, C. E.—Correction of erosion by afforestation.

McTaggart, A.—Grass types suited to erosion control.

208 Ratcliffe, F. N. Soil drift in the arid pastoral areas of South Australia. Coun. Sci. industr. Res. Aust. Pamphlet No. 64. 1936. pp. 84. A report of an investigation into soil drift in the arid pastoral areas of South Australia which receive an average annual rainfall of less than 10 inches. The rainfall is very variable. Two main types of vegetation are found in the region: "salt-bush shrub-steppe" (the "bush"), and "acacia semi-desert scrub" (mulga scrub). Data concerning the more important plant species are given. The greatest extent of erosion and drift has occurred in the "bush" country, where stocking (and not rabbits or drought) has been the direct cause of the destruction of the protective plant cover. The progress of the erosion process is described. It was concluded from the investigation that permanent settlement is possible only when the stocking is in equilibrium with the vegetation, and not merely exploiting the plant capital. The urgent need for readjusting the stocking policy of the arid pastoral country is emphasized. A reduction in the general level of stocking is at present the only available method of even partially rehabilitating these areas, and nothing that the botanist may ultimately achieve can abolish the necessity of placing the stocking on a permanent and scientific basis. It is recommended that investigations along certain lines be initiated, including the search for exotic sand-binding plants.

209 Ratcliffe, F. N. Further observations on soil erosion and sand drift, with special reference to South-Western Queensland. Coun. Sci. industr. Res. Aust. Pamphlet. No. 70. 1937. pp. 28. A discussion of the pastoral problems in the area lying between the 10-inch isohyet and the desert area centred in the Lake Eyre basin. Soil erosion does not appear to be prevalent in south-western Queensland, although a few examples noticed are described. The sandhills of this region are best regarded as part of the eastern desert-sandhills system, centred in the Simpson Desert. They are characterized by incomplete plant cover even in good seasons. The South Australian sandhills are markedly sterile. A general description of the vegetation is given. The popular conception of an actively encroaching desert is not borne out by the state of affairs in south-western Queensland. The problem of the future of pastoral settlement in the arid semi-desert belt of Australia is discussed in general terms.

210 Roe, R. Plant succession on wind-eroded Red Soil areas in the Maranoa District (Queensland). Abstract in *Rep. Aust. Ass. Adv. Sci.* 24. Section P (In press.) Observations on the natural succession on areas rendered bare by the removal of the surface soil are described. The pioneer species is *Calotis hispidula* and following ecesis, loose blown sand is caught in the debris of this plant, gradually building up a seed bed, which provides conditions suitable for the establishment of other species, until finally the bared area is restored to grass.

211 McTaggart, A. Grass types suited to soil erosion control. *J. Coun. Sci. industr. Res. Aust.* 12. 155-7. 1939. Grasses considered suitable for controlling soil erosion in various coastal, sub-coastal and sub-interior belts of Australia are enumerated and briefly discussed.

212 South Australian Soil Conservation Committee. Report of the Soil Conservation Committee, together with Maps and Appendices, South Australia. A comprehensive report which discusses the cause of erosion in semi-arid South Australia, the history of erosion in other countries, the special problems in South Australia, and their possible control.

213 Richardson, A. E. V. The problem of soil erosion in pastoral areas. *Pastoral Rev.* 45. 1055 and 1167. 1935. The importance of the problem of soil erosion, its magnitude in South Australia, the causes of soil erosion in the semi-arid pasture areas and the mallee districts, together with a discussion of the possible methods of controlling soil drift.

4. Physiology, Mineral Deficiencies

214 Paltridge, T. B. and Mair, H. K. C. Studies of selected pasture grasses. The measurement of the xerophytism of any species. Coun. Sci. industr. Res. Aust. Bull. No. 102. 1936. pp. 38. This paper deals with the measurement of xerophytism in grasses, in the light of experience with seventeen species. Plants of different species were grown under approximately similar (glasshouse) conditions, then removed from all contact with the soil, and allowed to dry out in the laboratory environment while being weighed at regular intervals. Subsequent wilting was determined by the cobalt paper method of Livingston and Shreve and the water balance of each species calculated from the experimental data. On the basis of these experiments, seventeen grasses have been classified under the following headings :—

(1) Mesophytes. A. True mesophytes. B. Xerophytic mesophytes.

(2) Xerophytes. A. Mesophytic xerophytes B. True xerophytes.

("True Xerophytes" lost more than 75 per cent of their total water content before wilting.)

215 Riceman, D. S. and Donald, C. M. A copper deficiency in plants at Robe, South Australia. 1. Preliminary investigations on the effect of copper and other elements on the growth of plants in a "coasty" calcareous sand at Robe, South Australia. Coun. Sci. industr. Res. Aust. Pamphlet No. 78. 1938. pp. 7-23. Certain aspects of the mineral nutrition of plants on the blown calcareous sand of the south-east of South Australia have been studied. Sheep grazing in this area

suffer from "coast disease." Marked improvement in yield and health of wheat, oats and barley resulted from the application of copper sulphate. The untreated cereals suffered from a disease identified with that known in Europe as "reclamation disease" or "Urbarmachungskrankheit." Pasture species, though showing some response to copper application, failed to make normal development in the field with the dressing employed. Under pot culture conditions, an equivalent dressing of copper gave normal development of subterranean clover. A pot technique is described by which applied phosphorus is shown to be satisfactorily available to plants growing on this soil. The influence of various other minor elements was studied. Other work on copper deficiency is briefly reviewed and discussed.

216 Riceman, D. S., Donald, C. M., and Piper, C. S. Response to copper on a South Australian soil. *J. Aust. Inst. Agric. Sci.* 4. 41. 1938. A technical note giving a preliminary account of the response of herbage species to copper sulphate on a coastal calcareous sand.

217 Ballard, L. A. T. The effect of nitrate supply on transpiration ratio in plants. *Aust. J. exp. Biol. med. Sci.* 11. 161-76. 1933. The effect of nitrate in reducing transpiration ratio, which is the ratio of water transpired to dry matter produced up to any point, is due not to an effect on the transpiration rate per unit weight of leaf but to an effect on growth. This effect is analysed into its various components.

218 Ballard, L. A. T., and Petrie, A. H. K. Physiological ontogeny in plants and its relation to nutrition. 1. The effect of nitrogen supply on growth of the plant and its parts. *Aust. J. exp. Biol. med. Sci.* 14. 135-63. 1936.

219 Petrie, A. H. K. A note on the relation of mineral nutrition to transpiration in plants. *J. Coun. Sci. industr. Res. Aust.* 5. 177-80. 1932. The effect of nitrate treatment in reducing the transpiration ratio of *Atriplex semibaccatum* cannot be explained in terms of reduction of the osmotic pressure of the cell sap. Other possible interpretations are discussed.

220 Petrie, A. H. K. The intake of ions by the plant and its relation to the respiration by the root. *Aust. J. exp. Biol. med. Sci.* 11. 25-34. 1933. A hypothesis is developed wherein four mechanisms are suggested as causing intake of ions by the plant from its environment. It is shown that, in terms of this hypothesis, the rate of intake may be dependent upon the rate of respiration of the absorbing region of the root. Some data are then presented which agree with the view that such a relationship holds.

221 Petrie, A. H. K. The drift of the content of potassium and calcium with age in plants. *Aust. J. exp. Biol. med. Sci.* 12. 99-110. 1934. A partial interpretation is presented of the characteristic drifts in the K and Ca contents of the whole of an annual or annually renascent plant, or of a single leaf or shoot thereof. K occurs in the plant entirely in the ionic state, in cell sap and cytoplasm. Ca, in addition to being present in the ionic state in these phases, is also fixed chemically and probably almost irreversibly. The amounts of sap and cytoplasm probably rise to a maximum at maturity and then decline. The absolute amount of K may be correlated with this drift, loss setting in at such time after maturity as the amounts in the two phases have reached an equilibrium. The same correlation, so far as concerns the rise, may hold for Ca, although here the accumulation is supplemented by fixation. Loss of Ca is probably prevented by low mobility and fixation. Provided the K-ion concentrations of these phases do not rise too rapidly, the fact that the percentages of sap and cytoplasm probably fall from adolescence to death may account for the decline in relative K content. The decline in relative Ca content cannot be analysed, since the drift in the rate of fixation is not known; but continued fixation may be a factor in the maintenance of the relative content after maturity. Some experimental data obtained with *Lolium perenne* conform, as far as can

be analysed, to this partial interpretation of the drifts.

222 Petrie, A. H. K. Physiological ontogeny in plants and its relation to nutrition. 3. The effect of nitrogen supply on the drifting composition of the leaves. *Aust J. exp. Biol. med. Sci.* 15. 385-404. 1937.

223 Petrie, A. H. K., and Williams, R. F. Physiological ontogeny of plants and its relation to nutrition. 5. The effect of nitrogen and phosphorus supplies on the respiration rate of the leaves. *Aust. J. exp. Biol. med. Sci.* 16. 347-60. 1938.

224 Petrie, A. H. K., and Wood, J. G. Studies on the nitrogen metabolism of plants. I. The relation between the contents of protein, amino-acids and water in the leaves. *Ann. Bot., Lond.* n.s. 2. 33-60. 1938. The results of experiments with *Lolium multiflorum* and *Phalaris tuberosa*, grown under conditions which were constant in certain respects, suggest that the net rate of formation of protein from amino-acids decreases with reduction in water content, although it is not indicated whether synthesis is decreased, or hydrolysis increased, or whether both are affected. It is shown incidentally that increasing the supply of NH_4 ions to the root causes, over a certain range, marked reductions in the water content of the leaves.

225 Petrie, A. H. K., and Wood, J. G. Studies on the nitrogen metabolism of plants. 2. Inter-relations among soluble nitrogen compounds, water and respiration rate. *Ann. Bot., Lond.* n.s. 2. 729-50. 1938.

226 Petrie, A. H. K., and Wood, J. G. Studies on the nitrogen metabolism of plants. 3. On the effect of water content on the relationship between proteins and amino-acids. *Ann. Bot., Lond.* n.s. 2. 887-98. 1938.

227 Richardson, A. E. V., and Trumble, H. C. The transpiration ratio of farm crops and pasture plants in the Adelaide District. *J. Dept. Agric. S. Aust.* 32. 224-44. 1928. The transpiration ratio of farm crops was found to vary from season to season with the variations in the intensity of the physical environmental factors during the growing period of the crop, and particularly during the period of maximum transpiration. The transpiration rate for cereals and pasture plants varied with the stage of growth at which the crop was harvested. Grasses and clovers produced dry matter at relatively low water cost during winter and spring, but in the final stages of growth transpiration was high in relation to dry matter production. The application of soluble phosphates resulted in a marked reduction in the transpiration ratio of pasture plants, especially in the early stages of growth.

228 Williams, R. F. Physiological ontogeny in plants and its relation to nutrition. 2. The effect of phosphorus supply on the growth of the plant and its parts. *Aust J. exp. Biol. med. Sci.* 14. 165-85. 1936.

229 Williams, R. F. Physiological ontogeny in plants and its relation to nutrition. 4. The effect of phosphorus supply on the total protein and soluble nitrogen contents and water content of the leaves and other plant parts. *Aust J. exp. Biol. med. Sci.* 16. 65-83. 1938.

230 Wood, J. G., and Barrien, B. S. Studies on the sulphur metabolism of plants. 1. Preliminary investigations on the effects of different external concentrations of sulphate, ammonia and cystine on the amounts of sulphur-containing compounds in leaves. *New Phytol.* 38. 125-49. 1939. External supply of nitrogen acts as a limiting factor in the formation of protein-sulphur from sulphate. Increasing the external supply of sulphate is accompanied by no change in protein-sulphur or cystine, but if the external supply of nitrogen is increased, both protein-sulphur and cystine increase in amount while the amount of sulphate decreases. It is also shown that, if cystine is applied externally to the plant, it is oxidized to inorganic sulphate in the plant, but brings about no change in amount of protein-sulphur. The plants used were *Phalaris tuberosa* and *Lolium multiflorum*.

231 Wood, J. G., and Barrien, B. S. Studies in sulphur metabolism. II. The effect of nitrogen supply on the amounts of protein-sulphur, sulphate-sulphur and of the value of the ratio of protein-nitrogen to protein-sulphur in leaves at different stages during the life cycle of the plant. *New Phytol.* (in press). 1939. Describes the changes in amounts of protein-sulphur and sulphate-sulphur during the growth cycle of plants of *Andropogon sorghum* var. *sudanense* subjected to three different manurial treatments of nitrogen. The amount of protein-sulphur decreases throughout the life cycle, but less rapidly than the amount of protein-nitrogen.

232 Wood, J. G., and Barrien, B. S. Studies in sulphur metabolism. III. On changes in amounts of protein-sulphur and sulphate sulphur in plants during starvation. *New Phytol.* (in press). 1939. During starvation in the dark of *Phalaris tuberosa* and *Lolium multiflorum*, protein-sulphur decreases in amount in the leaves and the amount of inorganic sulphur increases. No ethereal sulphates are present. There is no change in amount of protein-sulphur and sulphate in the stems and roots. In the leaves, protein-nitrogen also decreases, but the soluble nitrogen compounds formed during hydrolysis do not remain in the leaves, but migrate to stems and roots.

5. Technique of Pasture Investigations

233 Beruldsen, E. T., and Morgan, A. Irrigated pasture investigations. *J. Dept. Agric. Vict.* 31. 251-9. 1933. The technique adopted at Werribee, covering yield trials, grazing trials, botanical surveys, chemical analyses, watering and manuring methods.

234 Davies, J. Griffiths. The experimental error of the yield from small plots of natural pasture. Coun. Sci. industr. Res. Aust. Bull. No. 48. 1931. The variability of the yield of small plots of natural pasture was estimated in 1928 by cutting three-eighths of an acre of typical natural pasture in unit plots of 50 square links. The stancdard error of a unit plot of natural pasture is 32.5 per cent of the mean yield, a figure that is considerably higher than for field crops generally. The optimum size of the plot was 5 × 90 links, and ten replicates were required to reduce the error to 5 per cent.

235 Davies, J. Griffiths and Trumble, H. C. Notes on the technique of pasture investigations. Imp. Bur. Pl. Genet.: Herbage Plants. Bull. 14. 23-32. 1934.

236 Morgan, A., and Beruldsen, E. T. Sampling technique as applied to irrigated pastures. *J. Dept. Agric. Vict.* 29. 36-45. 1931. The errors associated with the quadrat sampling of an irrigated permanent pasture are discussed with the aid of statistical analyses. A technique has been developed, sampling before and after grazing by the use of a portable shearing machine, for determining the amount of feed consumed by the sheep on rotational grazing plots.

6. Legume inoculation, Nitrogen excretion

237 Strong, T. H. Lucerne seed "inoculation" in Queensland. *J. Aust. Inst. Agric. Soc.* 1. 113-4. 1935. An account of a successful trial of lucerne seed inoculation with an effective rhizobial strain in Queensland. A significant response to superphosphate was obtained in inoculated plots. A brief discussion of possible advantages in lucerne cultivation in Queensland is included.

238 Strong, T. H. Rhizobial strain variation in relation to the problem of lucerne seed inoculation. *J. Aust. Inst. Agric. Sci.* 2. 120-1. 1936. A brief account of a pot experiment in which a wide range in effectiveness of strains of *Rhizobium meliloti* to lucerne was demonstrated. Isolations of *Rhizobium* were made from lucerne from various centres and the cultures tested upon lucerne grown in a medium free from nitrogen. An account of a successful field trial of seed inoculation at the Waite Institute is given, a mixture of selected effective strains being used.

239 Strong, T. H. The influence of host plant species in relation to the effectiveness of the

Rhizobium of clovers. *J. Coun. Sci. industr. Res. Aust.* 10. 12-6. 1937. Strains of the clover-nodule producing organism, isolated from subterranean clover, proved effective with that species, but ineffective with red and white clover and vice versa. The organisms freely invaded all three hosts. The variation is due to specific host plant reaction, as distinct from variation due to "virulence". No strains proved highly effective on all three host plants.

240 Strong, T. H. Legume establishment and its function in relation to the development of some of the poor soils on Kangaroo Island. *J. Dept. Agric. S. Aust.* 41. 542-50. 1938. Soil and climatic conditions of Kangaroo Island are outlined and previous developmental methods criticized. The importance of the available phosphate level in relation to rhizobial and host plant factors is stressed, and the question of artificial inoculation with *Rhizobium* dealt with. Other factors relating to successful legume establishment are rainfall efficiency, soil preparation, the strain of clover employed and an absence of competition from associate grasses such as ryegrass.

241 Trumble, H. C. The grass-legume association in pastures. *J. Aust. Inst. Agric. Sci.* 1. 117-9. 1935. The concept of the grass-legume association as a basic unit of grassland is developed. The postulate is put forward that the combination of grass and legume is indispensible for maximum productivity, as well as for satisfactory animal nutrition. Fluctuations in the grass : clover ratio in pastures are attributed largely to variations in the relative supplies of available nitrogen and phosphorus in the soil. It is concluded that a transfer from legumes to an associate non-legume may occur, but that the question is not a simple one and is probably governed by variations in certain factors of the root environment.

242 Trumble, H. C., Strong, T. H., and Shapter, R. E. Investigations on the associated growth of herbage plants. Coun. Sci. industr. Res. Aust. Bull. No. 105. 1937. pp. 40. Three papers are included in the bulletin, the first forming a critical review of previous experiments on associated growth, accompanied by the results of pot culture investigations at the Waite Institute, which indicated that grasses are capable of deriving nitrogen from associated legumes during the vegetative stages of the latter in the winter-growing period of a semi-arid climate. Nitrogen became available as a result of nodule breakdown in these plants during senescence, and, in small quantities, from perennial legumes grown with artificial watering in spring and early summer, about twelve weeks after seeding. There is no foundation for the belief that, under South Australian conditions, legumes are capable of supplying the nitrogen requirements of associate non-legumes over the same growth interval. The second paper deals with the influence of nitrogen and phosphorus treatment on the yield and chemical composition of a grass and a clover, grown separately and in association, while the third deals with the associated growth of a perennial grass with annual legumes.

243 Cass Smith, W. P., and Pittman, H. A. J. The influence of methods of planting on the effective inoculation and establishment of subterranean clover. *J. Dept. Agric. W. Aust.* 16. 61-79. 1939. The inoculation of subterranean clover with an effective strain of rhizobial bacteria (*Rhizobium trifolii*) prior to planting has materially increased the yield, total nitrogen content and plant survival number. The methods of sowing inoculated subterranean clover seed in conjunction with superphosphate considerably influence the effective inoculation and hence the yield. The best practical methods of sowing are those in which the inoculated seed is planted at the same time as the superphosphate fertilizer, but when there is no contact, or the contact is momentary only and takes place just before the seed and fertilizer reach the moist soil.

244 Pittman, H. A. J. Leguminous crops and their place in the building up of soil fertility. *J. Dept. Agric. W. Aust.* 12. 105-16. 1935. The ideal system of maintaining or improving soil fertility is to grow leguminous crops from inoculated seed, liberally manure them with superphosphate and

potash, where these fertilizers are required, and subsequently feed them off, in situ, or plough them under, when well developed, to add their cheaply obtained nitrogen content to the soil, in a form in which other non-leguminous crops can use it. The history of the distribution of nitrogen-fixing bacterial cultures in Western Australia and details for their use on the farm are given. As an appendix, instructions for the preparation of legume root-soybean agar for the growth of nitrogen-fixing bacteria are given.

245 Pittman, H. A. J. Legume inoculation—Progress of the work in Western Australia. *J. Aust. Inst. Agric. Sci.* 2. 10-2. 1936. The early history of the pure culture method of legume inoculation in Western Australia.

7. Diseases and pests. Poison plants

246 Finnemore, H., and Jaffray, A. B. The amount of hydrocyanic acid in a blue couch grass, *Cynodon incompletus* Nees. *J. Coun. Sci. industr. Res. Aust.* 8. 136-8. 1935. A short paper discussing the lethal dose of plant material and the diminution in intensity of hydrocyanic acid reaction to test with drying and age of the plant material.

247 Smith, J. H. White grub damage to pastures on the Atherton Tableland. *Qd. Agric. J.* 46. 446-67. 1936. Entomological and ecological aspects of the white grub (*Lepidiota caudata*) problem are described in detail. A system of mixed farming is desirable in areas infested with the pest. Suggestions are made regarding the best time and methods of breaking up pastures. Pasture management and modifications in pasture types in relation to white grub activity are being investigated.

F. INDEX OF AUTHORS IN ABSTRACT SECTION

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